Partial Remedial Investigation and Feasibility Study for Port Gamble Bay

(a portion of the Port Gamble Bay and Mill Site)

Port Gamble, WA

FINAL

Prepared by

DEPARTMENT OF
ECOLOGY
State of Washington

Toxics Cleanup Program
Aquatic Lands Cleanup Unit
Washington State Department of Ecology
Lacey, Washington

December 2012

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This partial RI/FS (PRI/FS) was finalized in December 2012 and contains the Final Remedial Investigation for Port Gamble Bay and the Final Feasibility Study for Port Gamble Bay. The Port Gamble Bay Property is a portion of the Port Gamble Bay and Mill Site. This PRI/FS combines two focused Remedial Investigation and Feasibility Study Reports (RI/FS) that had previously been released for public review in early 2011. In response to comments received, Ecology performed additional sampling and integrated that with the separate reports into this comprehensive PRI/FS. The conclusions of the PRI/FS form the basis for the cleanup action to be implemented in Port Gamble Bay under a consent decree.

The titles of the documents that had previously been released for public comment in February and March 2011 were:

- Draft Remedial Investigation, Port Gamble Leased Area
- Draft Feasibility Study, Port Gamble Leased Area
- Draft Remedial Investigation, Sawmill Area
- Draft Feasibility Study, Sawmill Area

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Remedial Investigation
for
Port Gamble Bay

Port Gamble Bay and Mill Site
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LIST OF ACRONYMS

2LAET	second lowest apparent effects threshold
µg/kg	micrograms per kilogram
ABS	absorption fraction
AF	adherence factor
AFDW	ash-free dry weight
ARI	Analytical Resources, Inc.
AT	averaging time
BE	Biological Evaluation
BTV	background threshold value
BW	body weight
CAP	cleanup action plan
CDI	chronic daily intake
CF	conversion factor
CoC	chemical of concern
CoPC	chemical of potential concern
CSF	cancer slope factor
CSL	cleanup screening level
cPAHs	carcinogenic polynuclear aromatic hydrocarbons
DNR	Washington Department of Natural Resources
dw	dry weight
ECDF	empirical cumulative distribution function
Ecology	Washington State Department of Ecology
ED	exposure duration
EF	exposure frequency
EIM	Environmental Information Management System
EPA	Environmental Protection Agency
EPC	exposure point concentration
FI	fractional exposure
FLA	former lease area
FLTF	former log transfer facility
FS	feasibility study
HI	hazard index
HPAHs	high molecular weight polynuclear aromatic hydrocarbons
HQ	hazard quotient
IR	ingestion rate
KM	Kaplan-Meier
LAET	lowest apparent effects threshold
LDW	Lower Duwamish Waterway
MDL	method detection limit
MIG	mean individual growth

mg/kg	milligrams per kilogram
MLLW	mean lower low water
MRL	method reporting limit
MTCA	Model Toxics Control Act
ng/kg	nanograms per kilogram
OC	organic carbon
OCDD	octachlorodibenzo-p-dioxin
OCDF	octachlorodibenzofuran
PAHs	polynuclear aromatic hydrocarbons
PCA	principal components analysis
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-p-dioxins
PCDFs	polychlorinated dibenzofurans
pg/g	picograms per gram
PGST	Port Gamble S’Klallam Tribe
PQL	practical quantitation limit
PSEP	Puget Sound Estuary Program
QA-2	quality assurance level 2
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RfD	reference dose
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
RL	reporting limit
RME	reasonable maximum exposure
RPD	redox potential discontinuity
RSLs	regional screening levels
SAIC	Science Applications International Corporation
SAP	Sampling and Analysis Plan
SD	standard deviation
SIM	selective ion monitoring
SPI	sediment profile imaging
SQS	sediment quality standard
SMA	sediment management area
SMS	Sediment Management Standards
SRI	supplemental remedial investigation
SVOC	semivolatile organic compound
TCDD	tetrachlorodibenzo-p-dioxin
TEC	toxic equivalency concentration
TEF	toxic equivalency factor
TEQ	toxic equivalency quotient
TOC	total organic carbon
TVS	total volatile solids

UCL	upper confidence limit
UTL	upper tolerance limit
WAC	Washington Administrative Code
WHO	World Health Organization
ww	wet weight

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EXECUTIVE SUMMARY

This report presents the combined results of several remedial investigations performed from 2002 to 2011 by Pope & Talbot, Pope Resources, the Olympic Property Group, and the Washington State Department of Ecology (Ecology) near the former Pope & Talbot Mill and in Port Gamble Bay, Washington. The in-water portions of Port Gamble Bay and the Mill Site are addressed in this document and supporting Appendices A through C, while the Mill Site uplands are addressed in the RI/FS presented in Appendix D. Under Ecology's Toxics Cleanup Program Puget Sound Initiative, Port Gamble Bay is one of seven bays in Puget Sound identified for focused cleanup and restoration.

Port Gamble Bay is located in Kitsap County and encompasses more than 2 square miles of subtidal and shallow intertidal habitat. Pope & Talbot operated a sawmill on the northwest shore of the bay from 1853 to 1995, with log transfer and rafting activities occurring at various locations on the bay. Pope & Talbot leased 72 acres from the Washington Department of Natural Resources from 1970 to 2001 for temporary log storage and transfer purposes. Log rafting ceased in 1995 when the sawmill closed, and Pope & Talbot removed pilings from the leased area in 1996. The log sort yard and ramp operated from 1970 to 1995 and consisted of a dock and pilings on privately owned tidelands and an access road. Three landfills were also located along the western shoreline, some of which received mill waste and some municipal waste. The upland portions of all the landfills and the sediment area of one landfill were cleaned up in 2004 under Ecology's Voluntary Cleanup Program.

The bay and surrounding areas support diverse aquatic and upland habitats, as well as resources for fishing, shellfish harvesting, and many other aquatic uses. The area surrounding the bay remains rural in nature. The Port Gamble S'Klallam Tribal Reservation is located east of the bay, with extensive use of the bay by the tribe for shellfish harvesting, fishing, and other resources.

Current and Former Sources

Based on all of the investigations to date, the likely sources of contamination to Port Gamble Bay are:

- **Wood Waste.** Deposition of wood waste through log rafting, log transfer activities, chip loading, and other sources related to the former mill has resulted in thick deposits of wood chips, bark, and other debris both north and south of the mill site. Smaller amounts of wood debris can be seen at the former lease area and at various locations along the shoreline. In turn, these wood waste deposits generate a variety of breakdown products, including toxic chemicals, resulting in elevated levels of organic carbon, volatile solids, sulfides, ammonia, resin acids, and phenols in sediments.

- **Creosoted Pilings.** Thousands of creosoted pilings and overwater structures are present near the former mill site and in areas to the south, with varying degrees of structural integrity. These pilings and structures continue to release carcinogenic petroleum hydrocarbons, other chemicals, and wood debris to the aquatic environment.
- **Wood Burning and Hog Fuel Boiler.** Historic burning of large quantities of wood debris at the mill, originally on an uncontained slab and later in a hog fuel boiler, released large amounts of particles into the air. Based on the prevailing winds, much of this material would have settled out on the surrounding soils and in Port Gamble Bay, ultimately settling out into bottom sediments of the bay. Ash was also generated by these wood-burning activities, which may have been deposited in the landfills or in other nearby upland areas. The particles and ash contained petroleum hydrocarbons, dioxins/furans, and potentially metals.
- **Upland Mill Activities.** Other historic industrial activities at the mill may have contributed metals and organic chemicals along the southern and southwestern shoreline of the former mill.
- **Shoreline Debris.** Substantial shoreline debris is present at the former mill site, south along the shoreline in the landfill areas, and continuing further south along the western shoreline. The debris includes asphalted and creosoted materials, bricks, metal scraps, plastics, other landfill waste, and untreated wood. These materials may have contributed some of the chemicals seen in sandier areas along the beach.

Environmental Transport Pathways

Contaminants were transported to and around the bay in the following ways:

- **Currents and Tidal Fluctuations.** As wood deposits continue to break down near the mill through biological and chemical action, finer-grained organic material is produced, which appears to be transported through currents and tidal action to the south-central areas of the bay and deposited there. All of the same wood waste breakdown products observed near the mill are found in this south-central portion of the bay, along with very fine wood particles in the sediments.
- **Concentration of Clay Particles.** Similar transport processes concentrate very fine-grained natural sediments such as clays in the south end of the bay. Metals strongly bind to clay and were found to be highly correlated with the percentage of clay in the sediments. It appears that most metals in the bay are naturally concentrated at the south end of the bay due to deposition of clay particles there. Cadmium levels in the very southeast corner of the bay exceed levels of concern through these natural processes.
- **Aerial Deposition.** Particles containing chemicals from the wood burning activities at the former mill site would have been transported with the prevailing winds and deposited onto the surface

of Port Gamble Bay, where currents and tidal fluctuations would have eventually deposited these particles in the south-central areas of the bay.

- **Stormwater Runoff.** Stormwater runoff of contaminants from the former mill site occurred during and after its operation. Based on the investigations conducted, this transport pathway affected mainly intertidal sediments immediately adjacent to the site, primarily to the south and southwest of the former mill.

Ecological and Human Health Risks

- **Ecological Effects.** Detrimental effects to sediment-dwelling organisms have been evaluated through a variety of toxicity tests (laboratory bioassays) over 10 years of studies. Areas to the north and south of the former mill site consistently show toxicity in at least one of the tests used. Smaller areas in the former lease area and in the south-central portion of the bay also show toxicity. The bivalve larval bioassay appears to be the toxicity test that is most sensitive to wood waste breakdown products, and is of considerable concern due to the importance of shellfish reproduction in the bay. In addition, deep deposits of wood waste smother benthic organisms and provide an inhospitable substrate for recolonization, producing an environment largely devoid of sediment-dwelling organisms.

- **Human Health Risks.** Human health risks were calculated for tribal consumption of shellfish and exposure to beach sediments while clamming, scenarios that are also expected to be protective of recreational fishermen and other beach uses. Several chemicals, including arsenic, cadmium, carcinogenic petroleum hydrocarbons, polychlorinated biphenyls, and dioxin/furans have calculated human health risks from seafood consumption that exceed regulatory risk levels, both in Port Gamble Bay and in relatively clean areas of Puget Sound. These risks are associated with consumption of large quantities of shellfish; human health risks associated with use of the beach are below levels of concern.

  The majority of these calculated risks are associated with:

  - Natural geologic concentrations of arsenic,
  - Ubiquitous low-level concentrations of petroleum hydrocarbons and dioxins/furans, and
  - Calculations using the detection limit for undetected compounds.

  Of the remaining contaminants, cadmium and carcinogenic petroleum hydrocarbons exceed Puget Sound natural background concentrations throughout Port Gamble Bay, and dioxin/furan concentrations exceed natural background concentrations over limited areas near the mill site and offshore of the former log transfer facility. These chemicals are considered site-related and will be addressed through the cleanup.

Cleanup Standards

Under the cleanup regulations (Model Toxics Control Act, Chapter 173-340 Washington Administrative Code [WAC] and Sediment Management Standards, Chapter 173-204 WAC), the cleanup standard is set at the highest of:

- Risk-based concentrations (ecological or human health)
- Natural background concentrations
- Practical quantitation limits

Section 8 addresses human health risk, Section 9 presents comparisons of concentrations in sediments and shellfish at the site to natural background concentrations, and Section 11 describes how these are combined with practical quantitation limits to identify contaminants of concern and select site-specific cleanup levels. The following cleanup standards have been selected for Port Gamble Bay:

- **Toxicity due to wood waste breakdown products:** Numeric biological standards based on the results of toxicity tests described in WAC 173-204-320(3). This cleanup standard was set to protect sediment-dwelling organisms, including shellfish.
- **Carcinogenic petroleum hydrocarbons:** 16 micrograms per kilogram (µg/kg) based on the sum of carcinogenic compounds expressed as benzo(a)pyrene equivalents (see Section 8.2.4). This cleanup standard is based on natural background concentrations, which are higher than human health risk-based concentrations.
- **Dioxin/furan TEQ:** 5 nanograms per kilogram (ng/kg), based on the sum of dioxin/furan congeners expressed as 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents (see Section 8.2.4). This cleanup standard is based on practical quantitation limits, which are higher than both human health risk-based concentrations and natural background concentrations.
- **Cadmium:** 3.0 milligrams per kilogram (mg/kg). This cleanup standard is based on natural background concentrations, which are higher than human health risk-based concentrations.

Site Boundaries and Sediment Management Areas

Sediment management areas (SMAs) were developed to carry forward into the feasibility study for cleanup based on similar characteristics, such as types of contaminants, biological toxicity, geographic contiguity, and hydrologic considerations.

The following SMAs have been defined for Port Gamble Bay (Figure ES-1):

- **Mill Site North.** This SMA encompasses the embayment to the northeast of the former mill, between the jetty and the point. Mill Site North is characterized by deep wood chip deposits, large numbers of creosoted pilings and structures, biological toxicity, and high concentrations of wood waste breakdown chemicals and carcinogenic petroleum hydrocarbons.
- **Mill Site South.** This SMA extends south of the former mill site. This area is characterized by deep deposits of wood chips and bark and also contains significant numbers of pilings and overwater structures. Stations throughout this area are consistently toxic and also have high concentrations of wood waste breakdown chemicals, along with the highest levels of carcinogenic petroleum hydrocarbons in the bay. In addition, areas along the southern shoreline of the former mill have the highest dioxin/furan levels in sediments at the site.

- **Central Bay.** This SMA encompasses four stations showing biological toxicity in the south-central area of the bay that were colocated with elevated levels of wood waste breakdown products.
- **Former Lease Area.** This SMA includes a relatively small area in the former lease area characterized by biological toxicity and wood waste breakdown chemicals.
- **Carcinogenic Petroleum Hydrocarbons.** This large area includes all stations that exceed the cleanup standard for carcinogenic petroleum hydrocarbons in the bay. It also includes a smaller area offshore of the former log transfer facility that slightly exceeds natural background concentrations for dioxins/furans and the station at the southeast corner of the bay that exceeds natural background concentrations for cadmium. This SMA surrounds and includes all the other SMAs, and thus also serves as the site boundary.

SMAs may be refined further in the feasibility study, including subdividing and applying different cleanup alternatives to subareas of an SMA based on environmental benefit, technical feasibility, cost, integration with planned restoration alternatives, and other considerations.

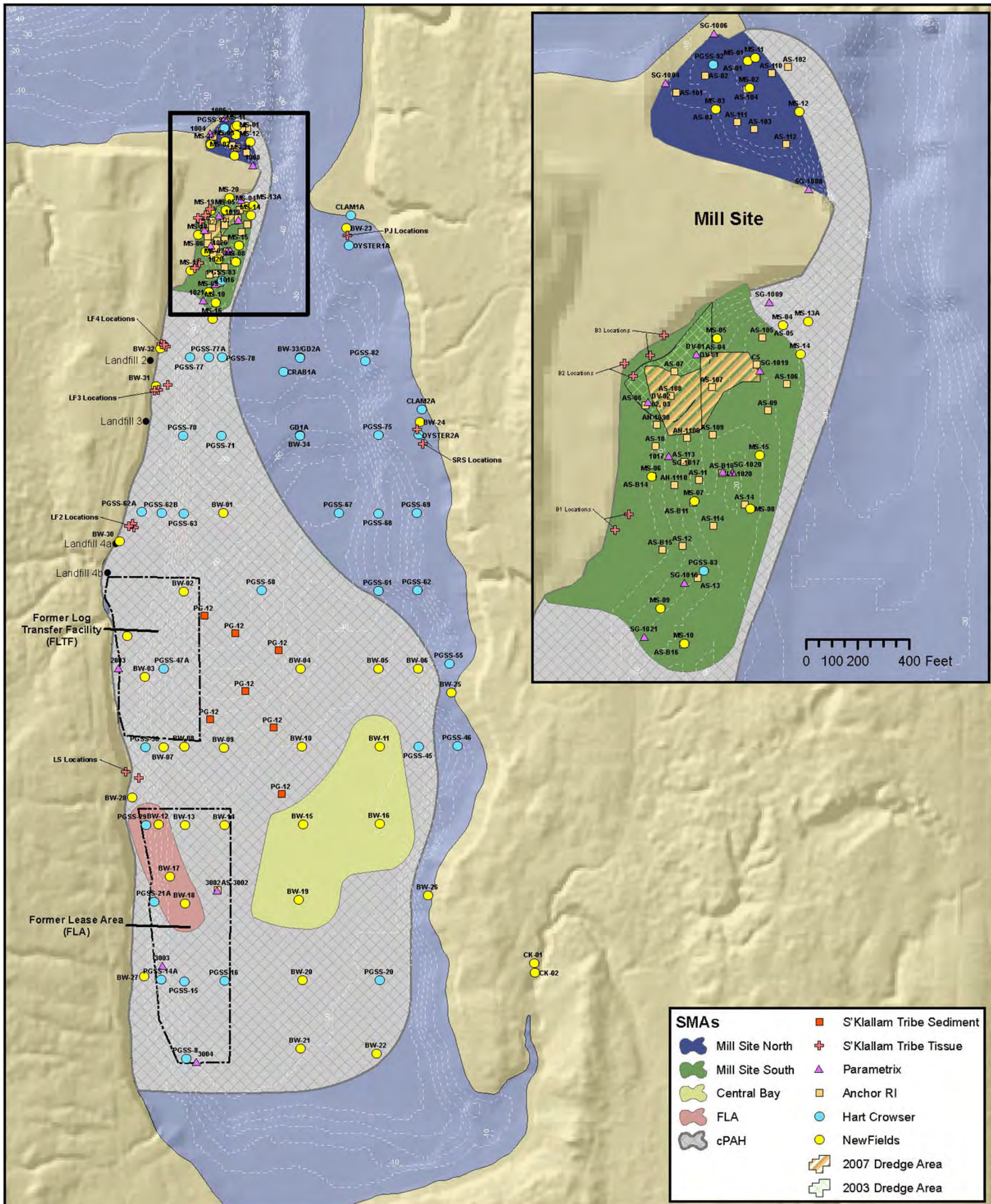

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Figure ES-1. Sediment Management Area Boundaries

0 1,000 2,000 4,000 Feet

1.0 INTRODUCTION

This report presents the combined results of several remedial investigations (RIs) performed on behalf of Pope & Talbot, Pope Resources, the Olympic Property Group, and the Washington State Department of Ecology (Ecology) near the former Pope & Talbot Mill and in Port Gamble Bay, Washington (Figure 1-1). The in-water portions of Port Gamble Bay and the Mill Site are addressed in this document and supporting Appendices A through C, while the Mill Site uplands are addressed in the RI/FS presented in Appendix D. Under Ecology's Toxics Cleanup Program Puget Sound Initiative, Port Gamble Bay is one of seven bays in Puget Sound identified for focused cleanup and restoration.

Port Gamble Bay is located in Kitsap County and encompasses more than 2 square miles of subtidal and shallow intertidal habitat just south of the Strait of Juan de Fuca (Figure 1-1). Pope & Talbot operated a sawmill on the northwest shore of the bay from 1853 to 1995, with log transfer and rafting activities occurring at various locations on the bay. Pope & Talbot leased the 72-acre portion of the former lease area (FLA) from the Washington Department of Natural Resources (DNR) from 1970 to 2001 for temporary log storage and transfer purposes (Parametrix 2002). Log rafting ceased in 1995 when the sawmill closed, and Pope & Talbot removed pilings from the leased area in 1996. Log rafting and sawmill activities were not conducted at the former log transfer facility (FLTF) or the FLA after Pope & Talbot removed the pilings in 1996. The FLTF log sort yard and ramp reportedly operated from 1970 to 1995 and consisted of a dock and pilings on privately owned tidelands and an access road (Parametrix 2003). Figure 1-1 also shows several landfills along the western shoreline, some of which received mill waste and some municipal waste.

Log rafting operations resulted in accumulations of wood waste on the bed of Port Gamble Bay near the sawmill. In addition, wood accumulations were suspected at both the FLTF and FLA based on the historic use of these areas (Figure 1-1). Temporary log storage and transfer within the 72-acre portion of the FLA and FLTF were reported from 1970 to 2001 (Parametrix 2002); however, historic log rafting activities also occurred much earlier in this area based on review of aerial photographs. The mill site and associated log transfer and log rafting activities are believed to have been the primary sources of impacts to the bay. Other possible sources of contamination include the former landfills, stormwater outfalls from Highway 101, and surface water drainages in the south and southeast portions of the bay.

The bay and surrounding areas support diverse aquatic and upland habitats, as well as resources for fishing, shellfish harvesting, and many other aquatic uses. The area surrounding the bay remains rural in nature. The Port Gamble S'Klallam Tribal Reservation is located east of the bay, with extensive use of the bay by the tribe for shellfish harvesting, fishing, and other resources.

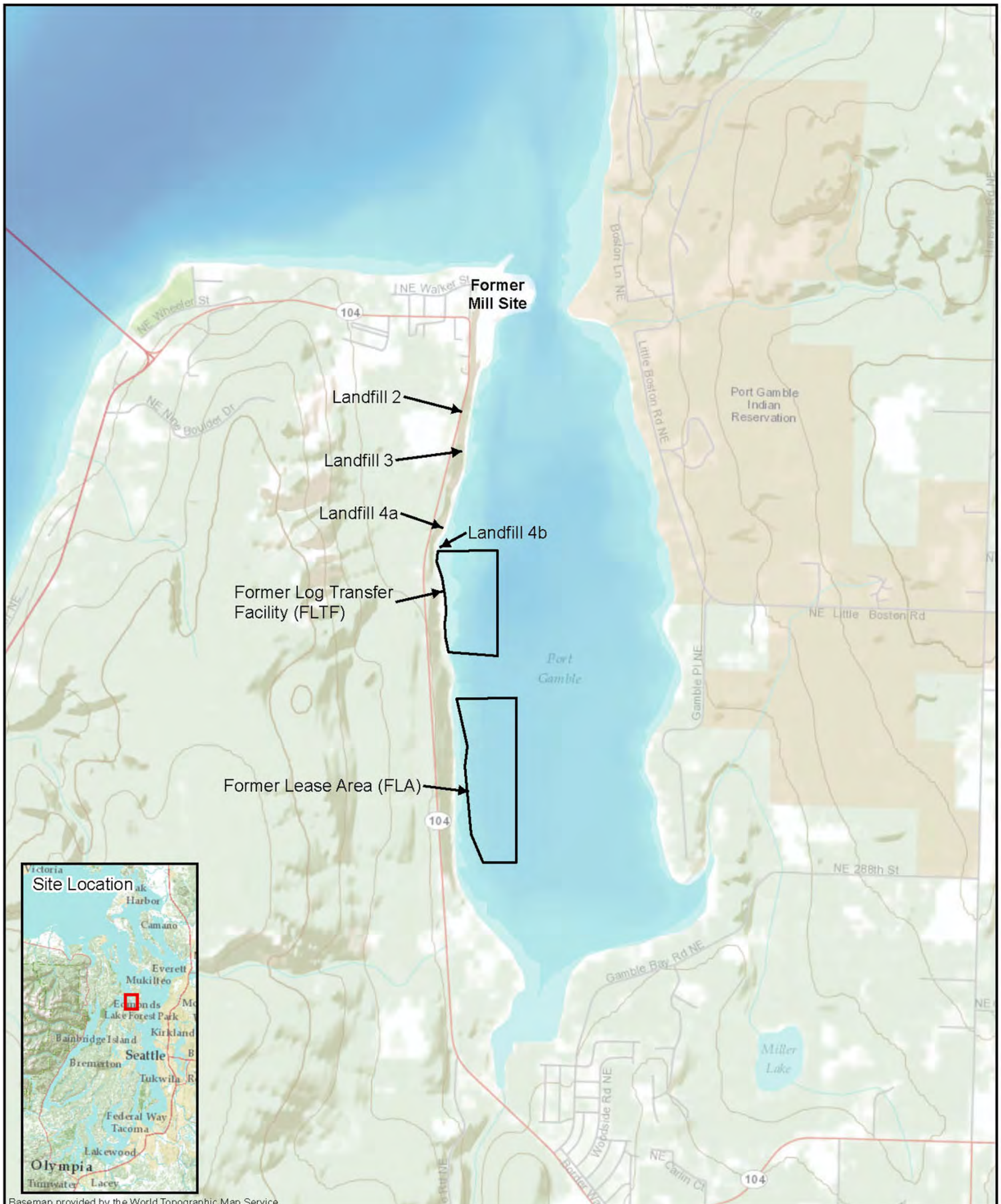

Figure 1-1. Overview of Port Gamble Bay

2.0 SEDIMENT REMEDIAL INVESTIGATIONS AND INTERIM CLEANUP ACTIONS

2.1 Remedial Investigations

As a consultant to Pope & Talbot, Parametrix conducted a series of investigations in Port Gamble Bay from 1999 to 2004 to identify chemical and wood waste impacts from sawmill operations on sediments and biota (Parametrix 2003a). While most of these data have been superseded by more recent investigations, in some areas near the mill these data represent the only information on Sediment Management Standards (SMS) chemicals of concern (CoCs). In areas where no other information is available, these data have been included (see Table 2 and Appendix A for a complete set of historic and current data relied on in this report).

In 2006, Anchor Environmental prepared a report compiling existing data for sediments near the former mill site and proposed a sediment investigation to fill data gaps (Anchor 2006a). A Biological Evaluation (BE) was also prepared (Anchor 2006b) as part of a cooperative interim sediment cleanup action involving approximately 16,500 cubic yards of subtidal sediment, as discussed further below. Much of this previous site investigation work was concentrated on aquatic areas near the sawmill, with only limited delineation of wood waste in other locations such as the FLTF and FLA. The areal and vertical extent of wood waste was not well defined for the purposes of evaluating impacts and potential remediation measures. In addition, chemical and biological quality were sparsely characterized beyond the aquatic areas near the mill. Thus, a complete assessment of impacts to human health and the environment could not be conducted.

Subsequently, Anchor, on behalf of Pope Resources and the Olympic Property Group, and Hart Crowser, on behalf of Ecology, simultaneously conducted RIs and feasibility studies (FS) for what were then termed the Mill Site and Baywide Site, respectively (Anchor 2009, 2010; Hart Crowser 2009, 2010). In addition, the Port Gamble S'Klallam Tribe provided some additional tissue and sediment data in 2010 and 2011 (PGST 2010, 2011). These investigations collectively provided a more complete assessment of impacts to biota near the mill and in other areas of Port Gamble Bay, as well as a preliminary basis on which to evaluate human health risks.

However, certain questions remained to be answered to finalize the RI, including a more complete assessment of other sources to the bay, a thorough evaluation of human health risks, comparison to natural background concentrations and risks, and refinement of biological effects boundaries. The bioassay protocols were refined to better reflect the fine-grained, flocculent nature of the sediments in some areas of the bay and address uncertainties in previous bioassay results. These additional field investigations were conducted by NewFields under contract to Science Applications International Corporation (SAIC) in July 2011. Details of the sampling and bioassay testing protocols are described in NewFields (2011a).

Specific tasks included:

- Collection of surface sediment chemistry samples to provide better delineation of site boundaries at the Mill Site, particularly along the eastern boundary, chip loading area, and areas with substantial pilings.
- Collection of composite sediment and shellfish samples from intertidal areas adjacent to potential upland source areas at the Mill Site to assess possible transport pathways and human health risks.
- Collection of intertidal sediment samples to identify any potential sources of contamination related to upland and/or shoreline activities away from the Mill Site, such as the landfills along the western shoreline, stormwater outfalls, or surface water drainages.
- Collection of surface sediment samples for biological testing using updated test protocols that take into account conditions found in Port Gamble Bay.
- Collection of additional composited crab tissue samples (edible muscle and hepatopancreas) from stations in the southern portion of Port Gamble Bay.
- Comparison of concentrations of bioaccumulative chemicals in sediments and tissues to natural background concentrations in Puget Sound to identify CoCs for human health.
- Development of cleanup standards for human health and ecological CoCs.
- Evaluation of human health and benthic toxicity data to identify areas exceeding the Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSLs) and use of this information to refine the boundaries of the sediment management areas (SMAs).

The primary goal of this investigation was to provide all of the remaining data necessary to evaluate human health and environmental risks throughout Port Gamble Bay sediments to enable completion of the FS and Cleanup Action Plan (CAP) for areas near the mill as well as Port Gamble Bay. The results of this final investigation along with the previously collected data supported combining the entire area into one site; thus, this report addresses both areas near the mill and in the larger Port Gamble Bay.

Anchor, on behalf of Pope Resources and the Olympic Property Group, previously submitted RI and FS Reports for the upland mill site (Anchor 2009, 2010) documenting a substantial amount of interim cleanup of the upland site and the results of soil and groundwater investigations. In addition, in 2011, the Port Gamble S'Klallam Tribe provided analytical results for a number of soil samples showing elevated levels of dioxins/furans in the vicinity of the upland mill site. Ecology will be working with Pope Resources and the Olympic Property Group to address any remaining issues on the upland mill site, including additional investigation of dioxins in soils and to provide closure for work already completed. These upland activities will be conducted separately to allow timely completion of the remedial investigation/feasibility study (RI/FS), CAP, consent decree, and cleanup for Port Gamble Bay.

2.2 Previous Dredging Activities and Interim Remedial Actions

Historic dredging likely occurred episodically near the mill area to maintain navigational depth and access; however, specific information on these events is not available. More recent dredging occurred in 2003 and 2007. In 2003, Pope and Talbot dredged approximately 13,500 cubic yards of sediment and wood waste from nearshore areas adjacent to the former sawmill. The 2003 dredging occurred over an elevation range of about -12 to -15 feet mean lower low water (MLLW) and was conducted to remove accumulated wood waste that reduced navigation access nearshore.

In 2007, an additional Interim Remedial Action dredging was performed to the east of the 2003 dredging area as a cooperative effort under the Model Toxics Control Act (MTCA) by Ecology, DNR, Pope & Talbot (currently bankrupt), and Pope Resources (Hart Crowser 2008b). Approximately 16,500 cubic yards of sediment and wood waste were removed from nearshore areas adjacent to the former sawmill. The 2007 dredging occurred over an elevation range of about -10 to -28 feet MLLW.

2.3 Known and Potential Sources of Contaminants

A summary of known and potential contaminants and their sources is provided below, which informed the design of the 2011 NewFields RI:

- **Wood waste and related contaminants.** As discussed above, many of the previous investigations and interim actions have focused on wood waste in sediments. Wood waste provides an inappropriate substrate for many benthic and epibenthic organisms to live on or in, and also impacts aquatic plants. In addition, ammonia, sulfides, and other toxic compounds can be generated during breakdown of wood waste in anoxic environments. At Port Gamble Bay, areas with abundant wood waste have elevated sulfides concentrations, but ammonia does not appear to be present at levels of concern. Finally, wood contains many other natural substances that can be present and toxic under certain circumstances, depending on the type of wood, the degree of processing, and environmental conditions. These chemicals include phenols, resin acids, and tannins. Some elevated levels of phenols and resin acids have been observed in areas of Port Gamble Bay with wood waste accumulations.
- **Polynuclear aromatic hydrocarbons (PAHs).** The primary source of PAHs to Port Gamble Bay is believed to be leachate from the thousands of creosoted pilings that are present near the Mill Site and along the northwestern shoreline, and historic burning of waste wood material at the mill over a period of 150 years. Additional sources may include surface water runoff from the mill, from Highway 101, and other paved surfaces; small fuel spills and discharges from vessels (including derelict vessels along the western shoreline); air deposition from combustion of petroleum, including vehicle and vessel exhaust; air deposition from wood stoves and backyard burning of yard waste; and natural background concentrations of PAHs in sediments from natural and regional sources. PAHs can be toxic to benthic organisms at high concentrations, but at the levels found in Port Gamble Bay are primarily of concern to human health due to the carcinogenicity of certain PAHs.

- **Metals.** Arsenic, cadmium, copper, and mercury have been identified as chemicals of potential concern (CoPCs) for human health. Sources of these metals beyond natural background concentrations in the bay are unknown, but could include landfill debris along the western shoreline, ash from the hog fuel boiler at the Mill Site, contributions from drainages to the south and southeast, vessel paints (particularly copper and mercury), and stormwater runoff. Arsenic was found in groundwater at the Mill Site, but is believed to be related to natural geologic conditions at the site based on multiple soil and groundwater investigations (Anchor 2010). No significant sources of these metals to sediments are known at the Mill Site, although some small areas of upland soils with metals contamination were removed during interim cleanup actions.
- **Polychlorinated biphenyls (PCBs).** PCBs have also been identified as potentially of concern for human health. Preliminary statistical analyses suggested that PCB concentrations may be within natural background concentrations; however, previously, there were not enough data to draw a definitive conclusion. In addition, only Aroclor data were available rather than congeners, which are more directly related to human health risk. PCB concentrations in regional sediments are related to global atmospheric deposition. Other sources to Port Gamble Bay sediments could include surface water runoff from several small PCB sources at the Mill Site, contributions from surface water drainages in the southern part of the bay, and landfill debris.
- **Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs).** PCDDs/PCDFs have also been identified as being of concern for human health. Preliminary statistical analyses suggested that PCDD/PCDF concentrations may be within natural background concentrations; however, there were not enough data to draw a definitive conclusion, especially in areas near the Mill Site. PCDD/PCDF concentrations in regional sediments are related to global atmospheric deposition as well as regional combustion sources and natural sources such as forest fires. Other sources of PCDDs/PCDFs may include surface water runoff and/or atmospheric deposition of particulates from the historic hog fuel boiler at the Mill Site, other local combustion sources including residential sources, and impurities in pentachlorophenol-treated wood.

3.0 SAMPLING AND ANALYSIS SUMMARY

Sampling and testing activities were conducted in general accordance with the protocols established in Ecology's (SMS) (Chapter 173-204 WAC), and Puget Sound Estuary Program (PSEP 1997a, 1997b, and 1997c), as referenced in Ecology's Sediment Sampling and Analysis Plan Appendix (SAPA) (Ecology 2008). The samples collected were acceptable for chemical, physical, and bioassay analysis, except where otherwise noted in Sections 4.0 through 7.0 below.

In addition to the most recent RIs, some data have been included from the historic investigations, as appropriate. These current and historic surveys and the types of data originally collected in each are summarized in Table 3-1. A complete list of the sediment and tissue samples included in the evaluations in this report and associated analyses are presented in Table 3-2. The locations and type of samples collected from each area are listed in Table 3-2 and presented in Figure 3-1, and station coordinates are shown in Table A-1 for all stations used in the RI Report. Complete tables of all data presented and analyzed in this RI Report are provided in Appendix A.

In general, when previous stations were revisited in later investigations, older data were replaced with newer data of the same type. Sediment chemistry data for metals, semivolatile organic compounds (SVOCs), PCBs, and dioxins/furans were used as far back as 2002 for locations where more recent data were not available. Sediment chemistry data for conventionals and sediment bioassay data were used as far back as 2006.

Table 3-1. Summary of Studies Incorporated into the Port Gamble Bay RI Report

			Mill Area[a]		Bay	
Study	**Collection Year**	**Reference**	**Sediment**	**Tissue**	**Sediment**	**Tissue**
NewFields	2011	NewFields 2011b	X	X	X	X
Port Gamble S'Klallam Tribe	2010	PGST 2010		X		X
Port Gamble S'Klallam Tribe	2011	PGST 2011			X	
Hart Crowser	2008	Hart Crowser 2009	X		X	X
Anchor	2006	Anchor 2006a	X		X	
Anchor	2007	Anchor 2009	X			
Anchor	2006	Anchor 2009	X			
Parametrix	2000	Parametrix 2004	X		X	
Parametrix	2002	Parametrix 2004	X			
Parametrix	2003	Parametrix 2004	X			

[a] The Mill Area is represented by the inset area in the figures.

The sections below provide a summary of the investigations previously conducted and interpreted in this RI report. Detailed descriptions of sampling and analysis methods, sample and core logs, chain of custody sheets, laboratory reports, and quality assurance (QA) reports can be found in the original references cited above.

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
Bay Subtidal Samples																			
11092801		PGST 2011			X	X		X	X	X	X	X		X					
11092802		PGST 2011			X	X		X	X	X	X	X		X					
11092803		PGST 2011			X	X		X	X	X	X	X		X					
11092804		PGST 2011			X	X		X	X	X	X	X		X					
11092805		PGST 2011			X	X		X	X	X	X	X		X					
11092806		PGST 2011			X	X		X	X	X	X	X		X					
AS-3002		Anchor 2006a	X		X	X												X	X
AS-3004		Anchor 2006a	X		X	X												X	X
PG11-BW-19-S		NewFields 2011b			X	X	X	X	X			X						X	X
PG11-BW-21-S		NewFields 2011b			X	X	X	X	X			X						X	X
PG11-BW-22-S		NewFields 2011b			X	X		X						X					
PG12		PGST 2011				X		X	X	X	X	X		X					
PGSS- 8		Hart Crowser 2009		X	X	X		X	X		X	X		X		X	X	X	X
PGSS-14A		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-15		Hart Crowser 2009		X	X	X		X	X		X	X				X	X	X	X
PGSS-16		Hart Crowser 2009		X	X	X		X	X		X	X				X	X	X	X
PGSS-18	PG11-BW-20-S	Hart Crowser 2009/NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X		X		X	X	**X**	**X**
PGSS-20		Hart Crowser 2009		X	X	X					X					X	X	X	X
PGSS-21A		Hart Crowser 2009				X		X	X		X	X				X			
PGSS-21B	PG11-BW-17-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-22	PG11-BW-18-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X		X		X	X	**X**	X
PGSS-29		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-29A	PG11-BW-12-S	Hart Crowser 2009		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
		/NewFields 2011b																	
PGSS-30	PG11-BW-13-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	**X**
PGSS-31	PG11-BW-14-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-33	PG11-BW-15-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X		**X**	X					X	X	**X**	**X**
PGSS-35	PG11-BW-16-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X		**X**	X			X		X	X	**X**	X
PGSS-38		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-38A	PG11-BW-07-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-39	PG11-BW-08-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	**X**
PGSS-40	PG11-BW-09-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	**X**
PGSS-42	PG11-BW-10-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	**X**	X	**X**	X	X				X	X	**X**	X
PGSS-44	PG11-BW-11-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-45		Hart Crowser 2009		X	X	X					X					X	X	X	X
PGSS-46		Hart Crowser 2009		X		X					X					X	X	X	X
PGSS-47	PG11-BW-03-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-47A		Hart Crowser 2009		X		X		X	X		X	X				X			

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PGSS-51	PG11-BW-04-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	**X**	X	**X**	X	X		X		X	X	**X**	X
PGSS-53	PG11-BW-05-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-54	PG11-BW-06-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-55		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-56	PG11-BW-02-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-58		Hart Crowser 2009		X	X	X		X	X		X	X				X	X	X	X
PGSS-61		Hart Crowser 2009		X		X					X					X			
PGSS-62		Hart Crowser 2009		X	X	X					X					X	X	X	X
PGSS-62A		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-62B		Hart Crowser 2009		X		X		X	X		X	X				X	X	X	X
PGSS-63		Hart Crowser 2009		X	X	X		X	X		X	X				X	X	X	X
PGSS-64	PG11-BW-01-S	Hart Crowser 2009		X	**X**	**X**	**X**	X		**X**	X	X		X		X	X	**X**	X
PGSS-67		Hart Crowser 2009		X	X	X					X					X	X	X	X
PGSS-68		Hart Crowser 2009		X		X					X					X			
PGSS-69		Hart Crowser 2009		X		X		X	X		X	X				X	X	X	X
PGSS-70		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-71		Hart Crowser 2009		X		X					X					X			
PGSS-73	PG11-BW-34-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**		**X**	X		X	X		X		X	X	X	X
PGSS-75		Hart Crowser 2009		X	X	X		X	X		X	X		X		X	X	X	X
PGSS-77		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-77A		Hart Crowser 2009		X	X	X		X	X		X	X		X		X	X	X	X
PGSS-78		Hart Crowser 2009		X		X					X					X			

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
PGSS-80	PG11-BW-33-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**		**X**	X		X	X		X		X			
PGSS-82		Hart Crowser 2009		X		X					X					X			
SG-3002		Parametrix 2004						X	X										
SG-3003		Parametrix 2004						X	X										
SG-3004		Parametrix 2004						X	X										
Mill Area Subtidal Samples																			
AN-1090		Anchor 2009				X													
AN-1100		Anchor 2009				X													
AN-1110		Anchor 2009				X													
AS-01	PG11-MS-01-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	X
AS-02		Anchor 2006a			X	X	X										X	X	X
AS-03	PG11-MS-03-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	X
AS-05	PG11-MS-04-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	**X**
AS-07		Anchor 2006a			X	X	X										X	X	X
AS-08		Anchor 2006a			X	X													
AS-09		Anchor 2006a			X	X	X										X	X	X
AS-10		Anchor 2006a			X	X													
AS-11		Anchor 2006a			X	X													
AS-12		Anchor 2006a			X	X	X												
AS-13		Anchor 2006a			X	X	X										X	X	X
AS-14	PG11-MS-08-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	X
AS-101		Anchor 2009			X	X	X										X	X	X
AS-102		Anchor 2009			X	X	X										X	X	X
AS-103		Anchor 2009			X	X	X												
AS-105		Anchor 2009			X	X	X												
AS-106		Anchor 2009			X	X	X										X	X	X

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AS-108		Anchor 2009			X	X	X										X	X	X
AS-109		Anchor 2009			X	X	X												
AS-110		Anchor 2009			X	X	X												
AS-111		Anchor 2009			X	X	X												
AS-112		Anchor 2009			X	X	X										X	X	X
AS-113		Anchor 2009			X	X	X										X	X	X
AS-114		Anchor 2009			X	X	X												
AS-B09		Anchor 2009															X	X	
AS-B11	PG11-MS-07-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	
AS-B14	PG11-MS-06-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	
AS-B15		Anchor 2009			X	X	X										X	X	X
AS-B16	PG11-MS-10-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	**X**
AS-B18		Anchor 2009			X	X	X										X	X	X
C5		Anchor 2009				X													
DV-01		Parametrix 2004						X	X	X		X							
DV-02		Parametrix 2004						X	X	X		X							
LY-1020		Parametrix 2004						X				X							
PG11-MS-05-S		NewFields 2011b			X	X	X											X	X
PG11-MS-09-S		NewFields 2011b			X	X	X											X	X
PG11-MS-11-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-12-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-13A-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-14-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-15-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-16-S		NewFields 2011b			X	X		X	X	X	X	X							
PGSS-83		Hart Crowser 2009				X		X	X		X	X							
PGSS-92		Hart Crowser 2009			X	X		X	X		X	X		X			X	X	X

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Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
SG-1016		Parametrix 2004						X	X										
SG-1017		Parametrix 2004						X	X										
SG-1019		Parametrix 2004						X	X										
SG-1020		Parametrix 2004						X	X										
SG-1021		Parametrix 2004						X	X										
Bay Intertidal and Creek Samples																			
PG11-BW-23-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-24-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-25-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-26-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-27-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-28-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-29-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-30-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-31-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-32-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-CK-01-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-CK-02-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-CK-03-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-CK-04-S		NewFields 2011b			X	X		X	X	X			X	X					
SG-2003		Parametrix 2004						X	X										
Mill Area Intertidal Samples																			
PG11-MS-17-S		NewFields 2011b			X	X		X		X			X	X					
PG11-MS-18-S		NewFields 2011b			X	X		X		X			X	X					
PG11-MS-19-S		NewFields 2011b			X	X		X		X			X	X					
PG11-MS-20-S		NewFields 2011b			X	X		X		X			X	X					
PG11-MS-21-S		NewFields 2011b			X	X		X		X			X	X					

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
PG11-MS-22-S		NewFields 2011b			X	X		X		X			X	X					
SG-1004		Parametrix 2004						X	X										
SG-1006		Parametrix 2004						X	X										
SG-1008		Parametrix 2004						X	X										
SG-1009		Parametrix 2004						X	X										
Bioassay Reference Samples																			
CR-20W		Hart Crowser 2009			X	X										X	X		
CR-23Mod		Hart Crowser 2009			X	X										X	X		
MSMP 43		Hart Crowser 2009			X	X										X	X		
PG11-CI-01-S		NewFields 2011b			X	X	X											X	X
PG11-CI-02-S		NewFields 2011b			X	X	X											X	X
PG11-CI-03-S		NewFields 2011b			X	X	X											X	X
Bay Tissue Samples																			
Clam #1A	Littleneck Clam	Hart Crowser 2009						X		X		X	X	X	X				
Clam 2A	Littleneck Clam	Hart Crowser 2009						X		X		X	X	X	X				
Crab 1-A Muscle Tissue	Dungeness Crab	Hart Crowser 2009						X		X		X	X	X	X				
Crab 1-A Pan2 (Hepatopancreas)	Dungeness Crab	Hart Crowser 2009						X		X		X	X	X	X				
GD Station #1A (PGSS-73)	Geoduck	Hart Crowser 2009						X		X		X	X	X	X				
GD Station #2A (PGSS-80)	Geoduck	Hart Crowser 2009						X		X		X	X	X	X				
LF2_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
LF2_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
LF2_M_PGST_100429	Manila Clam	PGST 2010						X		X		X			X				
LF2_O_PGST_100429	Oysters	PGST 2010						X		X		X			X				

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

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LF3_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
LF3_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
LF3_M_PGST_100429	Manila Clam	PGST 2010						X		X		X			X				
LF4_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
LF4_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
LF4_M_PGST_100429	Manila Clam	PGST 2010						X		X		X			X				
LF4_O_PGST_100429	Oyster	PGST 2010						X		X		X			X				
LS_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
LS_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
LS_M_PGST_100429	Manila Clams	PGST 2010						X		X		X			X				
LS_O_PGST_100429	Oyster	PGST 2010						X		X		X			X				
Oyster #1A	Oyster	Hart Crowser 2009						X		X		X	X	X	X				
Oyster #2A	Oyster	Hart Crowser 2009						X		X		X	X	X	X				
PG11-BW-04-DCH-R1	Dungeness Crab	NewFields 2011b						X		X			X	X	X				
PG11-BW-04-DCH-R2	Dungeness Crab	NewFields 2011b						X		X			X	X	X				
PG11-BW-04-DCM-R1	Dungeness Crab	NewFields 2011b						X		X			X	X	X				
PG11-BW-04-DCM-R2	Dungeness Crab	NewFields 2011b						X		X			X	X	X				
PG11-BW-30-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-BW-31-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-BW-32-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PJ_O_PGST_100429	Oyster	PGST 2010						X		X		X			X				
SRS_C_PGST_100429	Oyster	PGST 2010						X		X		X			X				
SRS_O_PGST_100429	Oyster	PGST 2010						X		X		X			X				
Mill Area Tissue Samples																			
B1_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
B1_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
B1_O_PGST_100429	Oysters	PGST 2010						X		X		X			X				

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
B2_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
B2_O_PGST_100429	Oysters	PGST 2010						X		X		X			X				
B3_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
B3_O_PGST_100429	Oysters	PGST 2010						X		X		X			X				
PG11-MS-17-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-18-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-19-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-20-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-21-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-22-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				

[a] Metals analysis include the SMS Metals: arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc.

[b] Conventionals include total organic carbon (TOC), total volatile solids (TVS), total solids, ammonia, and total sulfides.

[c] NewFields sample ID applies to samples collected at the same location as the previous Hart Crowser study.

X -Results from NewFields (2011b) replace or supplement previous data at this location.

SIM = selective ion monitoring, SVOC = semivolatile organic compound

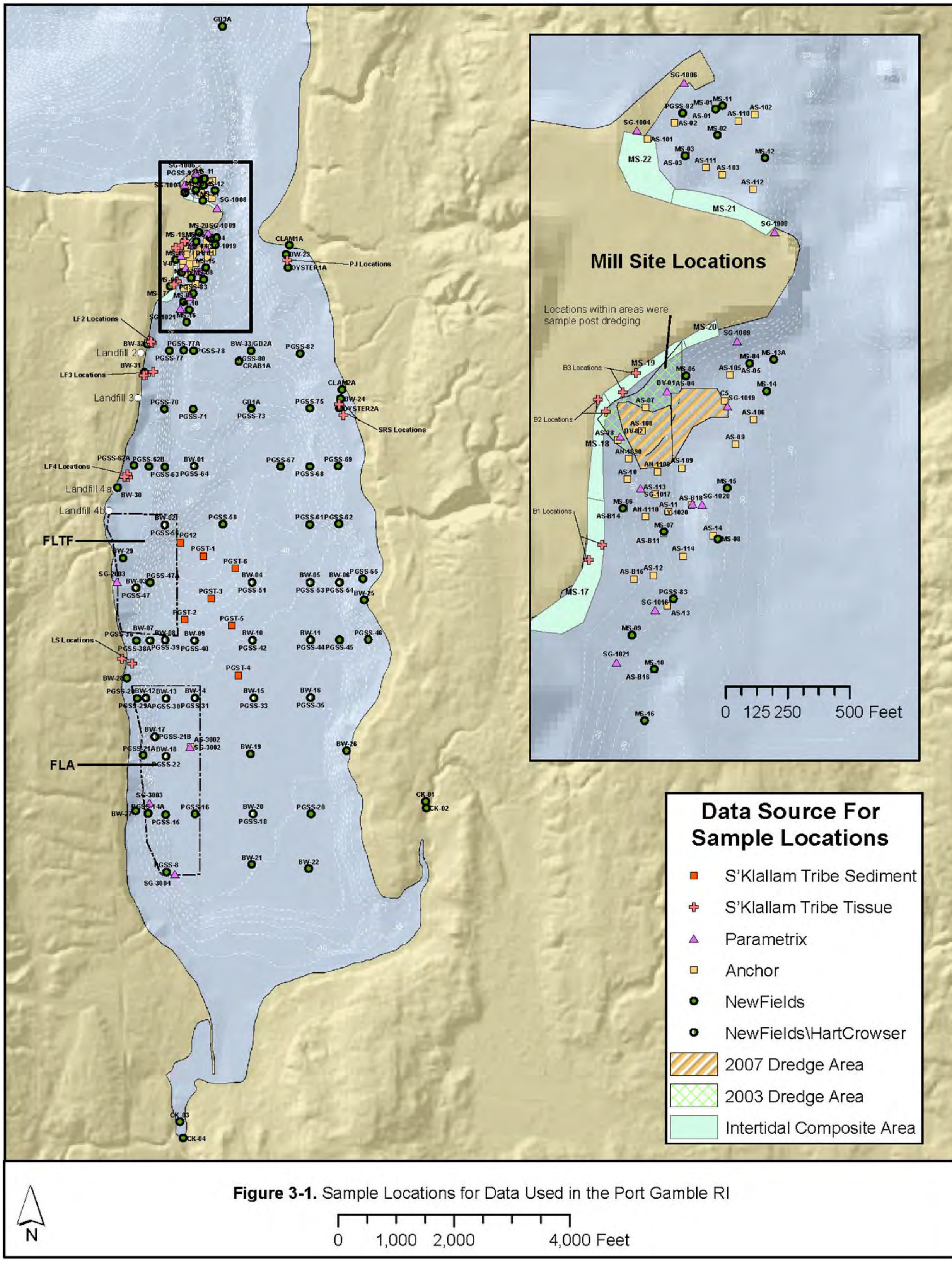

Figure 3-1. Sample Locations for Data Used in the Port Gamble RI

3.1 Sediment Profile Imaging/Plan View Images

During the Hart Crowser 2008 RI, sediment profile images (SPI) were collected from 120 subtidal locations in Port Gamble Bay and outside the mouth of the bay by SAIC of Bothell, Washington, under subcontract to Hart Crowser. Plan view (surface) photographs were collected at the majority of the locations. Samples were collected along multiple transects. Several locations were added to the original proposed locations along the shore of the bay to better delineate transitional areas and boundaries of potentially impacted sediments.

Three SPI images up to 20 cm (~8 in) depth were collected at each location. Plan view images of the surface (20×30 cm^2) were attempted at each location. Both SPI and plan view images were evaluated for the presence of wood waste and benthic organisms. The SPI report and SPI data are provided in Hart Crowser (2009) and interpreted in Section 4.

3.2 Sieved Samples

During the Hart Crowser 2008 RI, field staff performed sieving of subsamples to determine whether wood waste that was too small to be otherwise observed in bulk sediment was present. Six cores and 51 surface sediment samples were sieved using 0.5-mm and/or 1.0-mm sieves. Eight- to 16-oz jars of homogenized sediment were washed through the sieves and the amount of fine wood was visually estimated. Macrofauna and large polychaete tubes were removed from the sieve samples to facilitate more accurate estimate of wood waste volumes. The sieved samples were stored in ziplock bags and transported to Analytical Resources, Inc. (ARI) for archiving. The sieved samples were subsequently weighed, transferred to glass jars, and preserved with isopropyl alcohol. The preserved samples were then shipped to Ecology for additional microscopic examination.

3.3 Sediment Cores

During the Hart Crowser 2008 RI, 38 sediment cores were collected from subtidal locations within Port Gamble Bay to investigate the possible presence of wood waste and evaluate the types of subsurface sediments present. Twenty core locations were selected based on SPI image interpretation (six within the FLA/FLTF). Eighteen additional core locations were selected during sampling (four within the FLA/FLTF). Ten of the cores were collected in the FLA and FLTF since, based on historical log rafting practices, those were the areas of primary concern for wood waste. Each core was photographed and visually examined in general accordance with ASTM D 2488, Standard Practice for the Classification of Soils (Visual-Manual Procedure). Core logs and representative photographs are included in Hart Crowser (2009).

Two sediment core samples, 22B and 51B, were selected for radiometric dating. Radiometric dating was performed to determine sedimentation rates within the bay. Sedimentation rates were used to estimate the amount of deposition since mill operations began and to evaluate whether natural recovery is a viable cleanup alternative. Analysis was performed by Battelle

Marine Sciences Laboratory in Sequim, Washington. Cores were subsectioned into 80 2-cm-thick sections and selected samples were analyzed for ^{210}Pb and ^{137}Cs.

One sediment core (42) was selected for chemical analysis. Four sub-samples (0–0.5 ft, 1.5–2 ft, 3.5–4 ft, and 6.5–7 ft) were individually homogenized, placed in designated containers, and submitted to ARI of Tukwila, Washington, for analysis of grain size and conventional parameters.

3.4 Subtidal Surface Sediments

3.4.1 Parametrix 2002/2003 Investigations

Three surface sediment grab samples in the northwestern part of the bay and eight surface sediment grab samples collected near the mill were included in this RI Report, as these locations were not resampled in any of the subsequent investigations. Data for SMS metals and SVOCs from these samples were included in the data set for this RI Report to provide better spatial coverage for these analytes. Details of all of the sampling and analyses conducted during these investigations can be found in Parametrix (2004).

3.4.2 Anchor 2006 Mill RI

Data from 11 surface sediment grabs collected near the mill in 2006 were included in this RI Report. All of these samples were analyzed for conventionals and grain size, and four of these samples were also submitted for porewater sulfides and ammonia. In addition, these 11 samples were subjected to a full suite of bioassay tests, including amphipod 10-day mortality with *Eohaustorius estuarius*, larval abnormality and mortality with *Dendraster excentricus*, and the juvenile polychaete growth test with *Neanthes arenaceodentata.* Complete results of this investigation can be found in Anchor (2006a).

3.4.3 Anchor 2008 Supplemental Mill RI

Data from 18 surface sediment grabs collected near the mill in 2008 were included in this RI Report. All of these samples were submitted for conventionals analysis, and 14 of the samples were also submitted for grain size and porewater sulfides and ammonia analysis. Fourteen stations were also subjected to a full suite of bioassay tests, including amphipod 10-day mortality with *Eohaustorius estuarius*, larval abnormality and mortality with *Dendraster excentricus*, and the Microtox test. Complete results of this investigation can be found in Anchor (2009).

3.4.4 Hart Crowser 2008 RI

Fifty surface sediment grab samples were collected from subtidal locations within Port Gamble Bay and two sediment grab samples were collected outside Port Gamble Bay. Of these, 33 were colocated with core locations (nine within the FLA/FLTF). Three samples were collected at the same location as organisms collected for tissue analysis and two samples were colocated with the radiometric dating cores. Eighteen of the sediment grab sample locations were within the FLA and FLTF. In addition, three Carr Inlet reference samples were collected.

Sediment from these samples were submitted to ARI for analysis of conventional parameters and SMS chemicals. Analysis for conventional chemicals and resin acids was conducted on 52 sediment samples. Chemical analysis of SVOCs, polychlorinated biphenyls (PCBs), and SMS metals was conducted on 40 samples. Grain size analysis was performed on 32 sediment samples. Analysis for conventional chemicals and grain size was performed on the three reference sediment samples for bioassay testing.

Microtox 100% porewater testing was initially performed on a wide distribution of 52 stations and three reference stations to assess its utility as a screening tool for wood waste sites. Microtox testing was conducted by Nautilus Environmental of Tacoma, Washington. In addition, a full suite of bioassay toxicity testing for SMS decision-making purposes was performed on 32 surface sediment samples from the bay and three reference samples collected from Carr Inlet. The acute tests conducted included the 10-day amphipod survival test using *Eohaustorius estuarius and* the larval development test using *Mytilus galloprovincialis*. The chronic test conducted was the 20-day polychaete survival and growth test using *Neanthes arenaceodentata.* These bioassay samples were submitted to Northwestern Aquatic Sciences of Newport, Oregon for analysis.

3.4.5 Port Gamble S'Klallam Tribe 2010 Investigation

Seven surface sediment grab samples were collected from subtidal locations offshore of the FLTF in west-central Port Gamble Bay. Sediments from these samples were submitted to ARI for analysis of SMS metals, SVOCs, selected ion monitoring (SIM) PAHs, resin acids, PCB Aroclors, conventionals, and grain size. Sediments from these samples were also submitted to Axys for analysis of dioxin/furan congeners.

3.4.6 NewFields 2011 RI

Twenty-three surface sediment samples were collected from subtidal locations within Port Gamble Bay and three surface sediment samples were collected from Carr Inlet as reference samples. Most of these stations were colocated with stations sampled in the Hart Crowser 2008 RI. Three new stations (BW-22, 33, and 34) were added to provide additional chemistry in central and southern areas of the bay that were not previously sampled, and two of the sample locations (BW-19 and 21) had not previously had bioassays conducted.

All surface sediment samples were submitted for sediment conventional analyses, porewater sulfides and ammonia, and analysis of PAHs by the SIM method to obtain lower detection limits than in 2008. In addition, full SMS chemistry (metals, SVOCs, and PCB Aroclors) was analyzed at the two new bioassay stations, metals were analyzed at 5 additional stations in the center of the bay, and dioxins/furans were analyzed at three stations in the south/southeast area of the bay. Reference sediments from Carr Inlet, collected to support the bioassay testing, were submitted for sediment conventionals and porewater ammonia and sulfides.

Twenty-one samples from the bay and six reference samples from Carr Inlet were submitted for the larval development test using *Mytilus galloprovincialis.* Larval bioassays were run using the standard protocol as well as a recently developed protocol that minimizes entrainment of larvae due to fine-grained flocculent sediments such as are found in Port Gamble Bay. Both endpoints can be determined in the same samples and were run as a side-by-side comparison (see NewFields 2011a for details of the protocols). To test the new method, samples were selected from among the 2008 RI stations that passed SQS, stations that failed SQS, and stations that failed CSL, as well as two new bioassay stations for added spatial coverage.

In addition, the 20-day polychaete survival and growth test was rerun at seven stations within the bay as well as on three reference samples from Carr Inlet. This protocol has also been revised in line with national guidance to use the ash-free dry weight (AFDW) endpoint, which reduces variability in the biomass endpoint caused by sediment in the gut. This revised protocol can also be found in NewFields (2011a). Both sets of bioassays were conducted at NewFields, Port Gamble, Washington.

3.5 Intertidal Surface Sediments

3.5.1 Parametrix 2002/2003 Investigations

Five intertidal sampling stations near the mill were included in this RI Report, as these locations were not resampled in any of the subsequent investigations. Data for SMS metals and SVOCs from these samples were included in the data set for this RI Report to provide better spatial coverage for these analytes. Details of all of the sampling and analyses conducted during these investigations can be found in Parametrix (2004).

3.5.2 NewFields 2011 RI

During the NewFields 2011 RI, 14 intertidal sediment samples were collected from areas around the perimeter of the bay to evaluate potential sources of contamination to the bay and human health risks from exposure to intertidal sediments. Six samples were located along the western shoreline, and the northern three of these were colocated with tissue (clam) samples. Four samples were located along the eastern shoreline, and two samples each were located in creek drainages to the south and southeast of the bay.

Intertidal samples from 11 of the locations were collected during low tide using a stainless steel spoon or scoop. Composite samples were collected at intertidal stations BW-30, BW-31, and BW-32. All intertidal sediment samples and the intertidal creek samples were submitted for analysis of sediment conventionals, SMS metals and SVOCs, SIM PAHs, PCB congeners, and dioxin/furan congeners.

3.6 Biota

3.6.1 Hart Crowser 2008 RI

Biota sample locations were selected based on known areas where the Port Gamble S'Klallam Tribe collects shellfish for consumption and sale. Biota samples were collected by the Port Gamble S'Klallam Tribe Natural Resources Department using divers, traps, and hand collection. Proposed sample coordinates were provided to the tribe, and actual sample collection coordinates are listed in Hart Crowser (2009). The following organisms were collected:

- Geoducks (35 individuals) were collected at three subtidal sample locations near locations 73 and 80 (Geoduck 1 and 2, respectively), and location Geoduck 3. Three specimens were composited to obtain a single sample for each location. The skins on the necks of the geoducks were removed and archived. The gut ball was included in the meat composite.
- A crab trap was placed overnight to collect Dungeness crabs (8 collected) near location 80. All crabs were composited into a single sample, with muscle meat and hepatopancreas composited separately.
- Two oyster samples (45 total) and two littleneck clam samples (60 total) were hand collected from intertidal sample locations near locations 76 and 87. Oyster samples were composited from 15 oysters and clam samples were composited from approximately 30 individual clams.

In total, three geoduck samples, two oyster samples, two clam samples, and one crab sample (muscle tissue and hepatopancreas analyzed separately) were analyzed for percent lipids, metals, PCBs, and dioxins/furans to determine chemical concentrations in shellfish harvested for Tribal consumption and commercial sale.

3.6.2 Port Gamble S'Klallam Tribe 2010 Shellfish Sampling

In 2010, the Port Gamble S'Klallam Tribe conducted additional shellfish sampling at a variety of sites around Port Gamble Bay, including:

- Three samples of cockles, three samples of littleneck clams, three samples of manila clams, and two samples of oysters near the former landfills along the northwestern shoreline.
- One sample each of cockles, littleneck clams, manila clams, and oysters near the FLTF.
- One sample each of cockles and oysters near the south end of the Port Gamble S'Klallam Tribe reservation on the eastern shoreline.
- One sample of oysters at Point Julia as a reference sample.
- One sample each of cockles, manila clams, and oysters at a reference site outside the bay.

Oyster samples were composited from 15 oysters and clam samples were composited from approximately 30 individual clams. Samples were collected and composited by the Port Gamble S'Klallam Tribe and submitted to ARI for chemical analysis. In total, five cockle samples, four littleneck clam samples, four manila clam samples, and five oyster samples were collected from within the bay. All were submitted for analysis of percent lipids, metals, high molecular weight polynuclear aromatic hydrocarbons (HPAHs), and PCBs.

3.6.3 NewFields 2011 RI

Additional biota samples were collected to supplement the tissue data collected above, as follows:

- Native littleneck clam tissues (*Protothaca staminea*) were collected at three intertidal locations (BW-30, 31, and 32) along the northwestern portion of Port Gamble Bay, southwest of the former mill site. At each location, one to four individual clams were collected from ten discrete subsample stations (seven for BW-30). All clams from each subsample were then combined into one analytical composite sample per location. Clams were hand collected from each sampling location and were colocated with intertidal surface sediment samples.
- Two composite samples of Dungeness crab (*Cancer magister*) each consisting of six individuals were collected at BW-04 using a crab pot. Crab sampling was also attempted at BW-20, but no crabs were collected at that location.

Clam samples were depurated for 12 to 24 hours and then shucked to generate three analytical composites of 21, 28, and 38 individuals for stations BW-30, BW-31, and BW-32, respectively. Crab muscle tissue and hepatopancreas were composited as two separate analytical samples. After compositing, crab and clam samples were submitted to ARI and Axys for chemical analyses. Three intertidal clam samples collected from the northwestern shoreline of the bay and one crab sample were submitted for tissue analysis. Clam samples were analyzed for percent lipids, SMS SVOCs and metals, SIM PAHs, PCB congeners, and dioxin/furan congeners. The crab sample was analyzed for SMS metals, SIM PAHs, PCB congeners, and dioxin/furan congeners.

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4.0 SEDIMENT PHYSICAL CHARACTERISTICS AND OBSERVATIONS

Surface sediment samples and sediment cores were photographed, and visual observations and soil descriptions were documented in core logs presented in Hart Crowser (2009). Visual sample descriptions of surface sediment grabs and laboratory grain size reports are presented in Hart Crowser (2009) and NewFields (2011b).

4.1 Grain Size

The baywide distribution of sediment grain size ranged from very soft, clayey silt in low energy areas to very dense, coarse sand in high-energy areas of the bay near the Port Gamble Bay entrance. Baywide evaluation of sediment grain size is based on all available data including SPI images, surface sediment grab samples, and vibracores, and is shown in terms of percent fines in Figure 4-1. The complete grain size distribution is reported for each station in Appendix A.

In the southern and central portions of the bay, sediments generally consist of very soft, clayey silt (85–95% fines), indicating a low energy depositional environment. Sediments near the shoreline along the edges of the bay consist of silty sand to sandy silt in the shallow subtidal zones and transition to slightly silty sand to fine sand in the intertidal zones, indicating higher energy due to current and wave activity. Sediments near and within the northern bay entrance contained a higher proportion of coarse sand or gravel, reflecting the presence of strong tidal currents.

The laboratory also noted that 13 samples contained shells or shell hash, and/or organic matter or wood waste (PGSS-16, PGSS-21B, PGSS-29A, PGSS-38A, PGSS-39, PGSS-47, PGSS-51, PGSS-53, PGSS-56, PGSS-62, PGSS-73, PGSS-75, and PGSS-92). The shells or shell hash and/or organic material or wood waste were not removed prior to the grain size analysis.

4.2 Apparent Redox Potential Discontinuity

The apparent redox potential discontinuity (RPD) depth indicates the depth of oxygenation in the upper sediment column and generally reflects the degree of biogenic sediment mixing. As interpreted by SPI images, the distribution of mean apparent RPD depths in Port Gamble Bay ranged from 0.0 cm at station PG88 near the former mill site to a high of 5.53 cm at station PG19 in the fine-grained southern portion of the bay (Hart Crowser 2010, Figure 16). The mean apparent RPD depth for Port Gamble Bay was 2.77 cm. Relatively shallow apparent RPD depths (less than 2.0 cm) were generally measured in areas close to shore. At station 88 near the former mill site, SPI images show accumulation of wood chips on the sediment surface (Hart Crowser 2009). The deepest RPD depths (about 3–5 cm) were measured in fine-grained sediments present in the southern portion of the bay. At nine locations in the southern bay, the apparent RPD depth could not be measured due to overpenetration by the camera prism. However, apparent RPD depths at these locations are likely similar to surrounding RPD measurements.

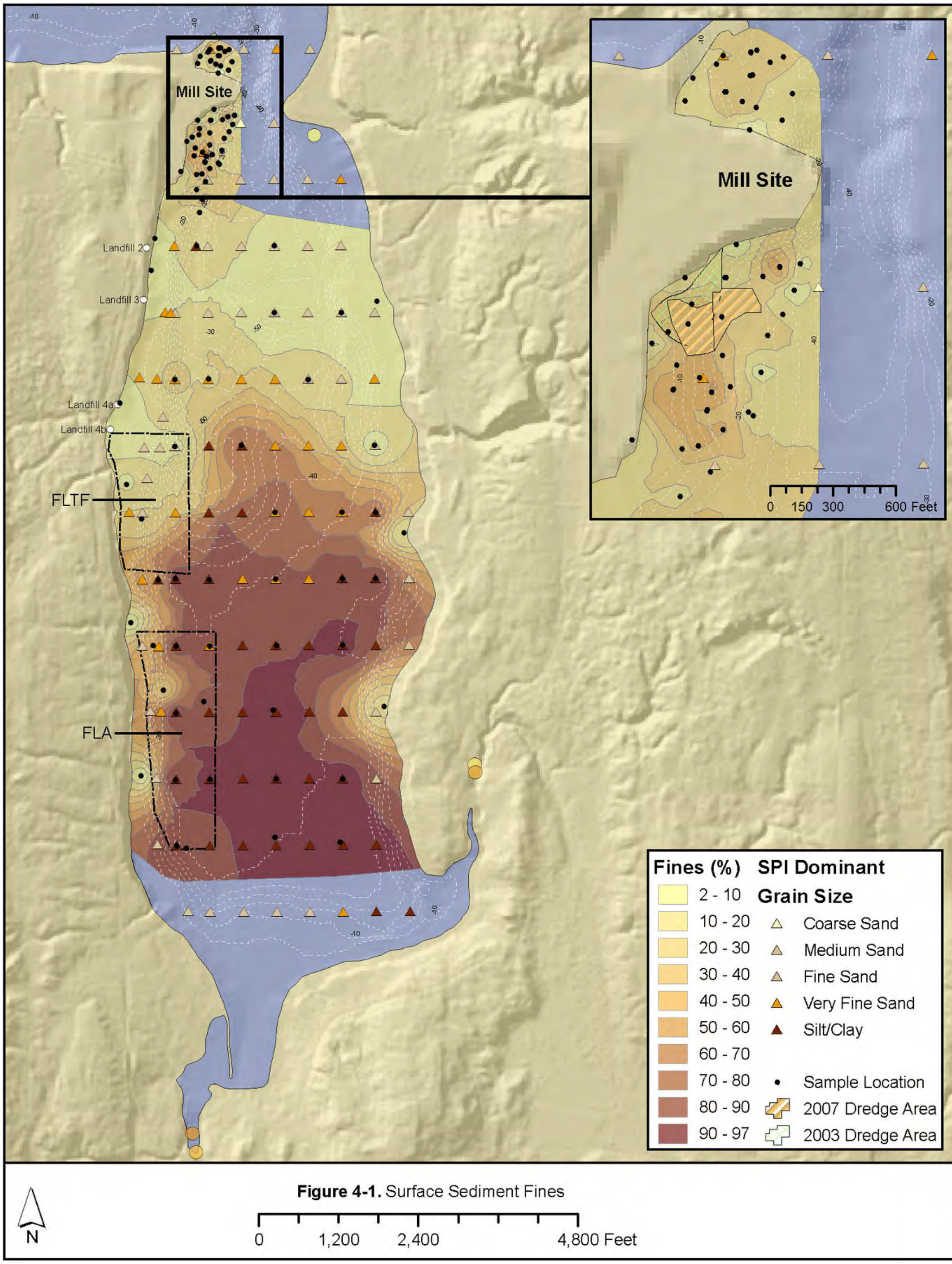

Figure 4-1. Surface Sediment Fines

4.3 Radiometric Dating Results

Sediment core dating makes use of radioisotopes ^{210}Pb and ^{137}Cs. ^{210}Pb is formed by the decay of gaseous ^{222}Rn, has a half-life of 22.3 years, and binds strongly to sediment. Dates are determined by the decrease in ^{210}Pb activity in subsurface sediments. ^{137}Cs owes its presence in the atmosphere to anthropogenic thermonuclear activities. ^{137}Cs deposition began around 1952 and peaked around 1963–1964. The sediment depth interval exhibiting ^{137}Cs activity should correspond to a ^{210}Pb-derived date between approximately 1952 and 1965.

Two sediment cores (locations 22 and 51) were submitted to Battelle for radiometric dating. Figure 4-2 presents calculated year versus depth of sediment. Based on ^{210}Pb dating results at both core locations, a sediment depth of approximately 50–55 cm (1.6–1.8 feet) would correspond to the year 1853, when sawmill operations began.

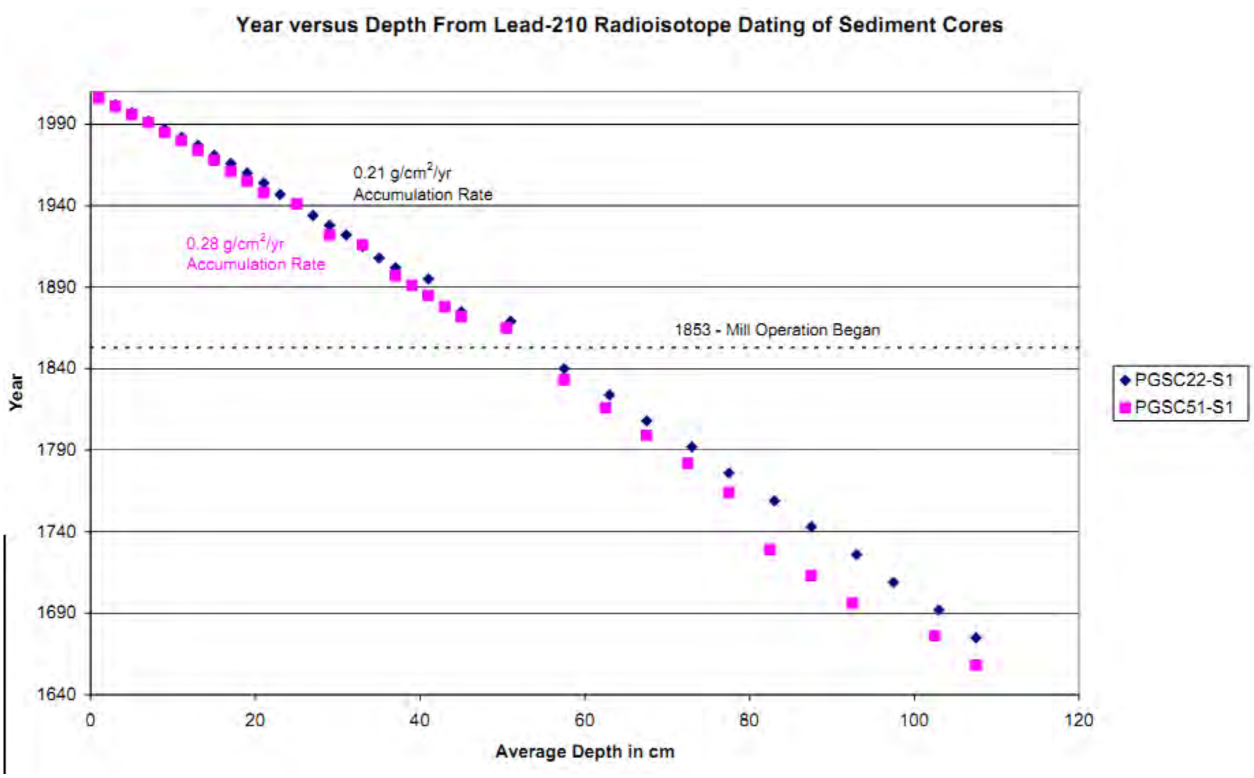

Figure 4-2. ^{210}Pb Radioisotope Dating Results (Source: Hart Crowser 2009)

^{210}Pb dating at location 22, toward the shore in the FLA, indicates an overall sediment accumulation rate of 0.21 g/cm^2-yr. Sediment accumulation rates cannot be calculated for shallower, more recent sediments due to surface mixing or for deeper, older sediment due to constant radioactivity levels from migration of radon from the earth. This accumulation rate corresponds to a sedimentation rate of 0.22–0.26 cm/year in sediment deeper than 60 cm and 0.43–0.48 cm/year in shallow (0–10 cm) sediment. This decrease in apparent sedimentation with depth may be due to consolidation and increased density of deeper sediments. The mixed layer at core location 22, as deduced from the ^{210}Pb data, appears to be from 0–14 cm depth. ^{210}Pb derived dates corresponding to the ^{137}Cs maximum peak ranged from 1947 to 1960. Assuming that sediment mixing or diffusion of cesium occurred, the dates estimated from ^{137}Cs analysis demonstrate reasonable agreement with the ^{210}Pb results.

For location 51, located in the center of Port Gamble Bay, the results of ^{210}Pb dating indicate a sedimentation rate of 0.28 g/cm^2-yr. This accumulation rate corresponds to a sedimentation rate of 0.31–0.33 cm/year in sediment deeper than 30 cm and 0.40–0.44 cm/year in shallow (0–10 cm) sediment. There was no apparent mixed layer in this core. ^{210}Pb-derived dates corresponding to the ^{137}Cs maximum peak ranged from 1955 to the present. The radiometric dating report and supporting data are presented in Hart Crowser (2009).

4.4 Distribution and Estimated Percentage of Wood Waste

SPI images, surface sediment grab samples, sediment core samples, and Ecology wet sieve samples from each location within the Port Gamble grid were observed for the presence of wood waste. Identification of wood waste was based on visual interpretation of SPI photographs and field interpretations and is subjective. For purposes of this report, wood waste included bark, wood chips, and wood particles, as well as terrestrial wood debris (i.e., twigs and pinecones). The baywide distribution of wood waste is presented in Figure 4-3 and the estimated percentage of wood waste for sediment samples are summarized in Table 4-1. Figure 4-3 presents combined near-surface and subsurface distribution based on SPI, plan view analysis, vibracores, and surface sediment samples.

Surface sediment grab samples and sediment core samples were evaluated in the field for the presence of wood waste. While wood waste was widely distributed, less than 5% by volume was estimated at most locations (Table 3). Greater amounts of bark material (visual estimates of up to about 50%) were generally observed at the base of the slope around the FLTF and FLA areas where historic log rafting and transfer occurred.

Wet sieving was also performed on samples from the upper 10 cm of sediment from 51 surface sediment samples and 6 sediment core samples using 0.5 mm and/or 1.0 mm sieves to determine whether wood waste that was too small to be observed in bulk sediment, was present. Sub-samples from the upper 10 cm of sediment contained approximately 5% by volume fine wood and wood fragments that were not otherwise visually obvious in the bulk sediment.

Wood waste was identified in:

- Either the plan view or SPI images in 28 of the 120 subtidal locations (approximately 23%).
- Eight of the 52 subtidal surface sediment sample locations (approximately 15%).
- Thirty of the 38 subtidal sediment core samples (approximately 79%).
- All of the 51 wet sieve surface sediment samples and the six wet sieve sediment core samples (100% of samples contained fine wood material).

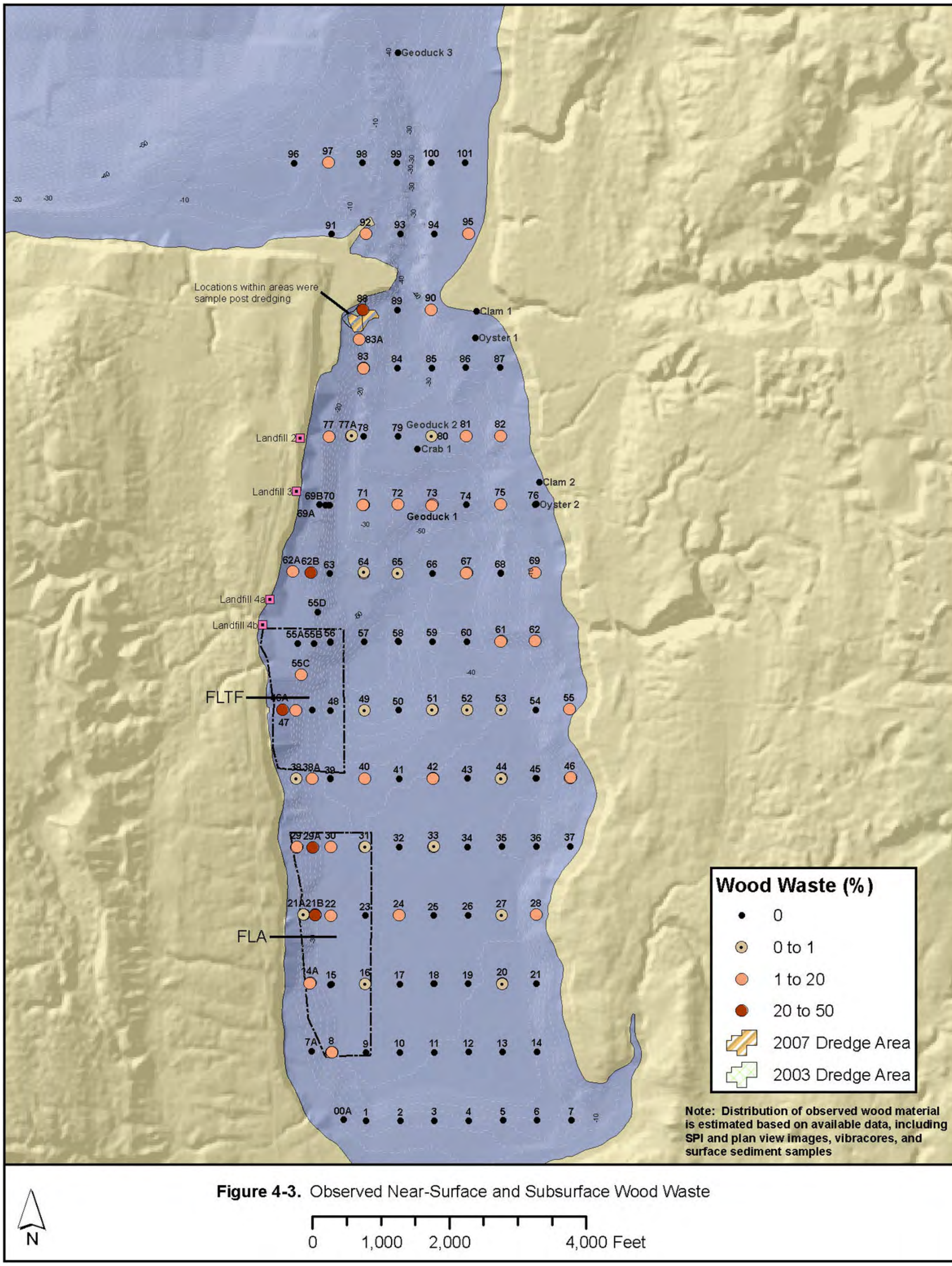

Figure 4-3. Observed Near-Surface and Subsurface Wood Waste

Wood waste was observed with the highest accumulations (15–50% cover) near the former sawmill operations at the mouth of the bay and nearshore within the FLA/FLTF. In many cases, these relatively high accumulations consisted of a single piece of wood. In contrast, wood waste was observed in trace accumulations (1–7%) in the northern and central portions of the bay.

Table 4-1. Wood Waste Observations in Surface Grabs and Subsurface Sediment Cores

Location ID	Estimated Percentage	Depth Beneath Sediment Surface (ft)			Notes
SPI Plan View					
47	1%	0			Leaf litter, stick upper right
SPI Image					
14A	2%	0.66			Wood waste (particles)
20	1%	0.66			Wood waste (particles)
21B	5%	0.66			Wood waste (particles)
24	2%	0.66			Wood waste (particles)
27	1%	0.66			Wood waste (particles)
28	7%	0.66			Wood waste (particles)
29A	50%	0.66			Large piece of wood waste on surface
30	3%	0.66			Wood waste (particles)
38	1%	0.66			Wood waste (particles)
46A	25%	0.66			Wood waste on surface
52	1%	0.66			Wood waste (particles)
55	1%	0.66			Wood waste (particles)
55C	2%	0.66			Wood waste (particles)
62	5%	0.66			Wood waste (particles), twig
62A	2%	0.66			Wood waste (particles)
62B	30%	0.66			Large piece of wood waste on surface
67	1%	0.66			Wood waste (particles)
71	2%	0.66			Wood waste (particles)
72	2%	0.66			Wood waste (particles)
73	15%	0.66			Large piece of wood waste on surface
81	3%	0.66			Wood waste (particles)
83A	20%	0.66			Large piece of wood waste on surface
88	30%	0.66			Large piece of wood waste on surface, leaves
90	5%	0.66			Wood chips 1 cm
92	15%	0.66			Wood waste (particles)
95	5%	0.66			Wood waste (particles)
97	2%	0.66			Wood waste (particles)
Sediment Core Samples					
8	5%	0 to 0.5	0.5 to 2.0		Wood waste (bark, wood chips)
16	1%	1	4.5		Bark piece, twig
22	5%	0 to 1			Wood waste (bark)
29	20%	0.5 to 1.6			Wood waste (bark, wood chips)
31	1%	3			Bark piece
33	1%	3.5			Twig
38A	20%	0 to 2.2			Wood waste (bark, wood chips)
40	5%	0 to 0.5	1.0 to 1.5		Wood waste (wood chips)
42	5%	0 to 0.5	1.5 to 2.0	6.5 to 7	Wood waste (bark, wood chips), twig and

Table 4-1. Wood Waste Observations in Surface Grabs and Subsurface Sediment Cores

Location ID	Estimated Percentage	Depth Beneath Sediment Surface (ft)			Notes
					pine cone
44	1%	0 to 0.5			Wood waste (bark, wood chips), twigs
46	2%	0 to 0.5	2		Wood waste (bark, wood chips)
47	20%	0 to 1			Wood waste (bark)
49	1%	2.3 to 2.5	7		Wood waste (bark)
51	1%	3.7	5.5	6.5	Wood waste (bark)
53	1%	1.5 to 2			Wood waste (wood chips)
55	20%	1.2 to 2.0	2.2		Wood waste (bark, wood chips)
61	5%	0 to 1.1	2.6		Wood waste (wood chips), twig
62	1%	0 to 0.3			Wood waste
62B	5%	0.5	1		Wood waste (bark, wood chips)
64	1%	1.5	2.2		Wood waste
65	1%	1.5 to 2			Wood waste (wood chips)
67	5%	0.30	1.3 to 2.1	3.7 to 6.4	Wood waste (bark, wood chips), twigs
69	5%	1.3 to 1.8			Wood waste (bark, wood chips), twigs
71	5%	0 to 0.5	0.5 to 1		Wood waste (bark, wood chips)
73	20%	0 to 0.5	1	2	Wood waste (bark, wood chips)
75	20%	0.4	1.5		Wood waste (bark, wood chips)
77	15%	0 to 0.5	0.5 to 1		Wood waste (bark, wood chips)
78	1%	0			Wood waste (bark, wood chips)
80	1%	0	0 to 0.5		Wood waste (bark)
82	2%	0 to 0.5	1.3 to 1.6		Wood waste (bark, wood chips)
Surface Sediment Samples					
21A	1%	0.66			Twig
21B	25-50%	0.66			Wood waste (bark)
29A	5%	0.66			Wood waste (bark, wood chips), twig
38A	5%	0.66			Wood waste (bark)
61	1%	0.66			Twig
73	5%	0.66			Wood waste (bark, wood chips)
83	5%	0.66			Wood waste (bark)
92	5%	0.66			Wood waste (bark, wood chips)

Source: Hart Crowser 2009

A summary of the SPI observations and interpretation relative to the presence of near-surface wood waste is presented in SAIC's SPI Survey Report in Hart Crowser (2009) and in Figure 4-3. Identification of sawdust and wood chips in SPI images was based on visual interpretation of photographs and is subjective. Wood waste was identified in either the plan view or SPI images in 28 of the 120 subtidal locations (approximately 23%).

4.5 Distribution of Benthic Organisms

Marine biological organisms, including macroalgae and invertebrates, were identified at most of the locations. Marine animals, macroalgae, or burrows were identified at 89% of the locations, based on reviews of the SPI and plan view images and sediment core and grab sample observations.

4.5.1 Marine Organisms

The majority of organisms were observed and identified in the sediment surface grab samples. Small fish were present in four grab samples. Sipunculids (peanut worms) were present at the bottom of three grab samples at approximately 1 ft below mudline. Other worms, including polychaetes, nemerteans, and worm tubes were identified in 37 grab samples. Cnidarians, including sea whips, sea pens, and a sea anemone, were identified in four grab samples. Arthropods, including shrimp, crabs, and barnacles were identified in 12 grab samples. Mollusks, including clams, a nudibranch, a limpet, and a piece of geoduck siphon, were present in eight grab samples. Shells, shell fragments, and shell hash were recorded in 32 grab samples. Echinoderms, including a sea cucumber and brittle stars, were observed in two grab samples, while sand dollars were identified in photographic images. Additionally, a tunicate (sea squirt) was caught on the Young grab sampler frame (Hart Crowser 2009).

The distribution of benthic organisms generally followed the bottom substrate type and grain size distribution in Port Gamble Bay. Geoducks and other organisms favoring sandy bottom conditions were generally present in shoreline areas and the northern half of the bay. Infaunal deposit-feeding organisms associated with fine-grained, unconsolidated soft bottom classifications were generally observed in the southern end of the bay.

Infaunal transitional organisms, including shallow-dwelling bivalves or tube-dwelling amphipods, were also observed in the middle portion of the bay, where the transition from fine-grain unconsolidated sediments to more consolidated sandy sediments occurs. Infaunal high energy organisms, including tubicolous and surface-dwelling polychaetes, were observed in the northern portion of the bay, where hard sandy consolidated sediments with higher bottom current energy are present.

Several locations in Port Gamble Bay also exhibited the presence of eelgrass (*Zostera* sp.) and other macrofauna such as sea pens (*Ptilosarcus gurneyi*) and sea whips (order Pennatulacea). Intact eelgrass beds were observed in locations north of the bay entrance (94, 97, 98, and 100), and just south of the entrance along the eastern shore (locations 82, 86, and 87). Eelgrass detritus (i.e., decomposing eelgrass blades, loose strands) was observed at locations 54 and 88. Sea pens and sea whips were observed at several locations in the northern portions of Port Gamble Bay. These organisms are known to position themselves in the path of currents in order to ensure a steady supply of food (e.g., plankton).

4.5.2 Benthic Habitat Type

The benthic habitat classifications in Port Gamble Bay generally followed the grain size major mode distribution measured from SPI images (Hart Crowser 2009). The greatest number of locations consisted of a hard, fine sandy bottom. Medium sandy hard bottom and medium sandy hard bottom with gravel were observed at 4% and 2% of the locations, respectively. The two stations with sandy hard bottom and gravel were located within the entrance channel to Port Gamble Bay. Hard sandy bottom classifications were generally found in shoreline areas and the northern half of Port Gamble Bay. One location within the entrance channel to the bay (location 89) consisted of a hard rock or gravel bottom. Location 88, near the former mill site, did not have a benthic habitat classification due to the high accumulations of wood debris on the sediment surface.

The second most predominant habitat classification (33%) was an unconsolidated soft bottom with very soft silts/clays. Silty unconsolidated soft bottom and sandy/silty unconsolidated soft bottom were also observed at 11% and 7% of the locations, respectively. The unconsolidated soft bottom classification was predominant in the southern reaches of Port Gamble Bay (Hart Crowser 2009).

4.5.3 Infaunal Successional Stage

The majority of infaunal successional stages observed in SPI images collected in Port Gamble Bay were Stage I (65%). Stage I infauna are typically the first organisms to colonize the sediment surface. These opportunistic organisms may include small, tubicolous, surface-dwelling polychaetes.

Stage III or Stage I on III comprised 31% of SPI locations, mainly associated with the more sandy substrate in the northern half of the bay. Stage III is a high-order successional stage consisting of long-lived, infaunal deposit-feeding organisms. Stage III invertebrates may feed at depth in a head-down orientation and create distinctive feeding voids visible in SPI images. Stage I taxa can persist in these areas, as they are opportunistic feeders, and are commonly associated with a Stage III community (Rhoads and Germano 1986).

Infaunal successional stage was indeterminate at five locations (4%) due to camera prism overpenetration or the presence of abundant wood debris.

In sandy substrates, such as the areas along the shoreline and the northern portion of Port Gamble Bay, the climax communities consisted primarily of surface dwellers (e.g., amphipods) that reside in the upper 1 cm of the sediment, as well as filter feeders including clams and geoducks not observed in the SPI images. These community types are classified as Stage I communities and are reflective of an area influenced by physical factors and the presence of a sandy substrate.

A higher order successional stage would typically be assigned to a climax community in a depositional environment consisting of a silt/clay substrate, such as areas in southern Port Gamble Bay. Localized feeding of large, deep-burrowing infauna (Stage III taxa) in these depositional environments result in distinctive excavations called feeding voids. Location 18 provides a representative example of feeding voids visible in southern Port Gamble Bay (Hart Crowser 2009).

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5.0 SEDIMENT CHEMISTRY RESULTS

This section presents analytical results for all of the sediment samples listed in Table 3-1. The various data sets from 2002–2011 have been combined for a more comprehensive interpretation. Both intertidal and subtidal chemistry are discussed and presented together in the following sections and on the figures. Complete data tables for all sediment samples are presented in Appendix A.

Results of the sediment chemical analysis were compared to applicable SMS marine criteria, including SQS and CSL thresholds, as described in WAC 173-204-320 and WAC 173-204-520. The marine SQS and dry weight (dw) equivalent lowest apparent effects threshold (LAET) numerical chemical concentration criteria define the degree of sediment quality that is expected to cause no adverse effects to biological resources in marine sediments. At concentrations at or below the CSL or dry weight equivalent second lowest apparent effects threshold (2LAET), effects to biota are expected to be minor. CSL and 2LAET represent the upper bound of minor adverse effects and above these concentrations, effects are anticipated to be significant.

5.1 Data Quality Review Summary

Overall, the data quality objectives, as set forth in Hart Crowser (2008a) and NewFields (2011a), were achieved, and these recent data are acceptable for use, as qualified. For some analytes, the two RIs had different data quality objectives; specifically, the supplemental RI had lower method detection limits/ method reporting limits (MDLs/MRLs) for several analytes to facilitate natural background comparisons and human health evaluations.

During the Hart Crowser 2008 RI, 22 non-detected sample results for neoabietic acid were rejected during the quality assurance/quality control (QA/QC). Results for other chemicals associated with wood waste were acceptable, so there is no significant impact to the data. Results for several analytes were qualified as estimated concentrations based on minor exceedances of quality control criteria. For some samples, reporting limits (RLs) for chlorinated benzenes, hexachlorobutadiene, butylbenzylphthalate, phenol, and 2,4-dimethylphenol were above SQS and/or dry weight equivalent criteria. When analytes were present, the laboratory reported estimated results to the MDLs, which were below the SQS and dry weight criteria for all analytes. Detailed chemical data quality review and chemical laboratory certificates of analysis are presented in Hart Crowser (2009).

All sediment and tissue samples in the NewFields (2011b) supplemental RI were submitted to EcoChem Inc., Seattle, Washington, for a level quality assurance level 2 (QA-2) validation (Environmental Protection Agency [EPA] Stage 3/4). The data were reviewed using guidance and quality control criteria documented in the *Combined Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP)* (NewFields 2011a) and the USEPA National Functional Guidelines. For some samples, detection limits for hexachlorobenzene, 1,2,4-trichlorobenzene, and hexachlorobutadiene were above the SQS criteria. Porewater ammonia and sulfides were analyzed as part of the NewFields supplemental RI following the procedures described in the SAP (NewFields 2011a). Porewater results did not undergo independent data validation. Detailed chemical data quality review and chemical laboratory certificates of analysis are presented in NewFields (2011b).

Sediment and tissue data collected by the Port Gamble S'Klallam Tribe were independently validated by Ecochem, Inc. Holding times were exceeded for mercury and the conventional parameters. QA results for earlier surveys can be found in the respective RI Reports listed in Table 3-1.

5.2 Conventional Parameters

Total organic carbon (TOC) concentrations in subtidal surface sediment samples ranged from 0.327–5.04% in the bay, with concentrations ranging up to 12.8% near the mill in areas of high wood waste (Table 5-1, Figure 5-1). TOC concentrations in the 10 intertidal sediment samples around Port Gamble Bay were generally low at <1%, while in the four creek samples to the south and southwest, TOC ranged from 2.41–8.19%. Aside from wood-impacted areas near the mill, TOC was generally lower in the northern half of the bay where currents are higher and was highest in the south-central part of the bay and in the FLA.

Total volatile solids (TVS) concentrations ranged from 0.46–20.06% in the bay, and similar to TOC, ranged up to higher levels near the mill, with a maximum of 44%. In the intertidal samples around Port Gamble Bay, TVS ranged from 0.56–1.95%, while in creek samples it was much higher, ranging from 4.49–18.04%. TVS followed a similar pattern overall to TOC, with high concentrations in the south-central portion of the bay.

Another indicator of the presence of organic loading such as wood waste and the overall availability of organic matter contained in sediment is the TVS/TOC ratio. Typical, unimpacted marine sediment has a TVS/TOC ratio <2 (personal communication, Jack Word, NewFields). Conversely, ratios >2 are often indicative of labile organic matter such as wood waste that is available for chemical or microbial breakdown. This often results in anaerobic conditions and elevated concentrations of sulfides. TVS/TOC ratios for Port Gamble Bay sediment samples are presented in Figure 5-2. Samples containing the highest TVS/TOC ratio are located toward the center of the bay where sediments are flocculent and fine-grained, as well as south of the former mill. This south-central part of the bay appears to be a location where fine-grained organic matter has come to be located through tidal and current action, and coincides with areas of bioassay exceedances (see Section 7).

Total sulfide concentrations in the bay ranged from 0.05U to 1,060 mg/kg, with the highest concentrations generally in the south-central part of the bay (Figure 5-3). Higher concentrations up to 3,220 mg/kg are found in areas near the former mill. Intertidal samples also ranged widely, from 1.13U to 418 mg/kg. The highest intertidal concentrations were at the FLTF and in the creek samples. Elevated sulfide concentrations are due to microbial decomposition of excess organic matter, are indicative of organic-rich anaerobic sediment, and may be associated with low oxygen. Samples containing the highest sulfide concentrations are located toward the central portion of the bay and within the FLTF and FLA, generally colocated with visual wood waste presence and locations with higher TVS/TOC ratios.

Table 5-1. Summary of Sediment Conventionals Results

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
Conventionals in %												
Preserved Total Solids	52	52	23.1	80.3	52.7	77.4	18	18	28.1	73	52	71.9
Total Organic Carbon	61	61	0.327	5.04	2.52	3.94	45	45	0.27	12.8	3.79	7.73
Total Solids	61	61	27.2	84.2	51.1	75.6	45	45	33.8	84	53.5	74.1
Total Volatile Solids	61	61	0.46	20.06	6.45	10.6	44	44	0.74	44.1	12.2	26.1
Conventionals in mg/kg												
Sulfide	52	52	1.44	1060	307	838	18	18	2.96	3220	571	1290
N-Ammonia	59	59	2.75	53.6	18.2	39.9	18	18	2.87	105.1	26	60.4
Intertidal Samples												
Conventionals in %												
Preserved Total Solids	14	14	45.3	83.9	69.2	79.9	6	6	74.00	83.2	79.1	82.9
Total Organic Carbon	14	14	0.254	8.19	1.85	5.21	6	6	0.24	4.78	1.26	2.82
Total Solids	14	14	39	86.6	71.7	83.9	6	6	76.70	86.73	82.3	86
Total Volatile Solids	14	14	0.56	18.04	3.09	5.87	6	6	0.61	3.17	1.36	2.28
Conventionals in mg/kg												
Sulfide	14	11	1.13	418	99.7	280	6	6	1.25	288	79	191
N-Ammonia	14	14	3.3	22.8	9.15	15.4	6	6	1.03	22.2	5.88	13.5

Non-detects included in descriptive statistics.

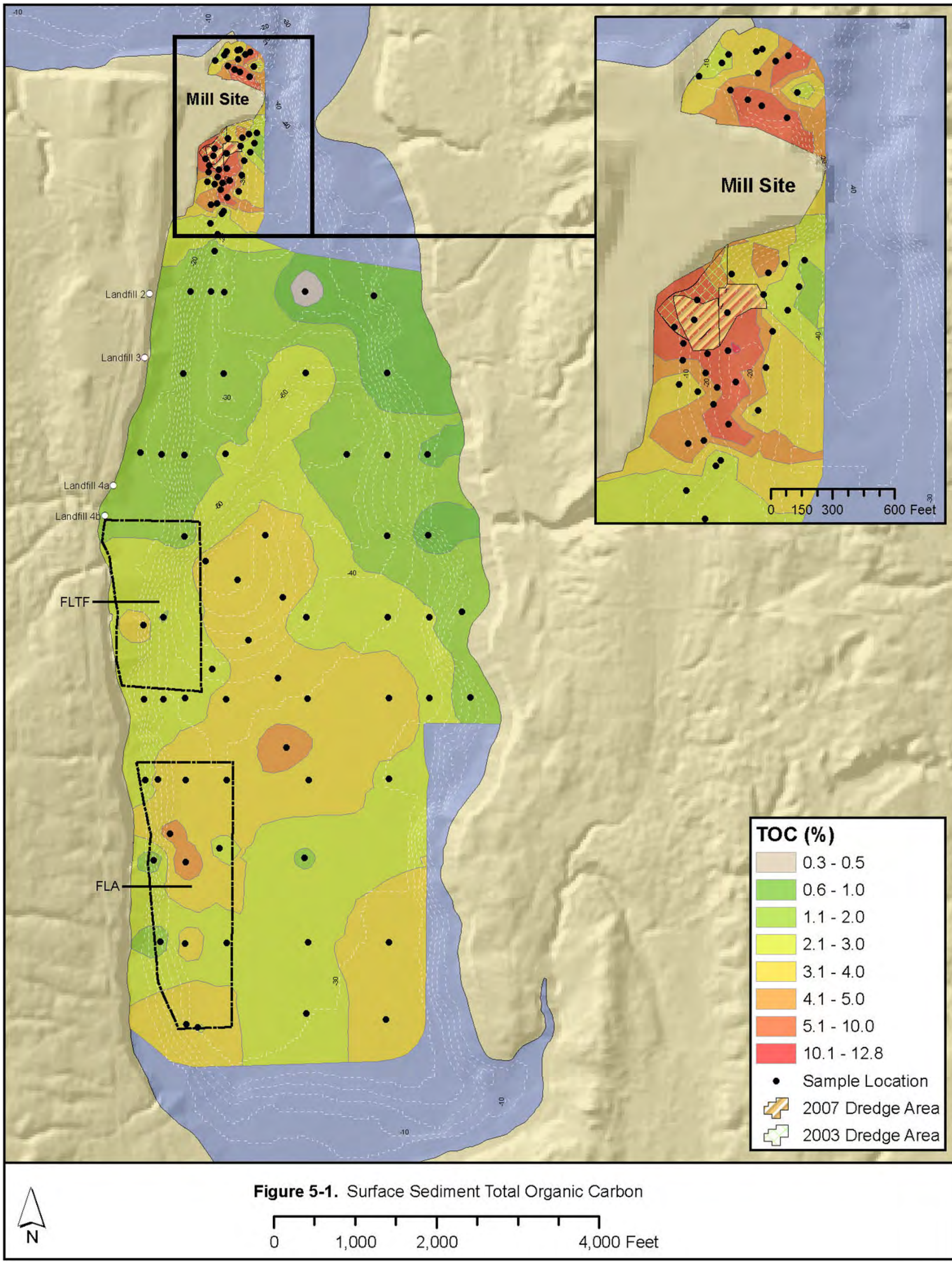


Figure 5-1. Surface Sediment Total Organic Carbon

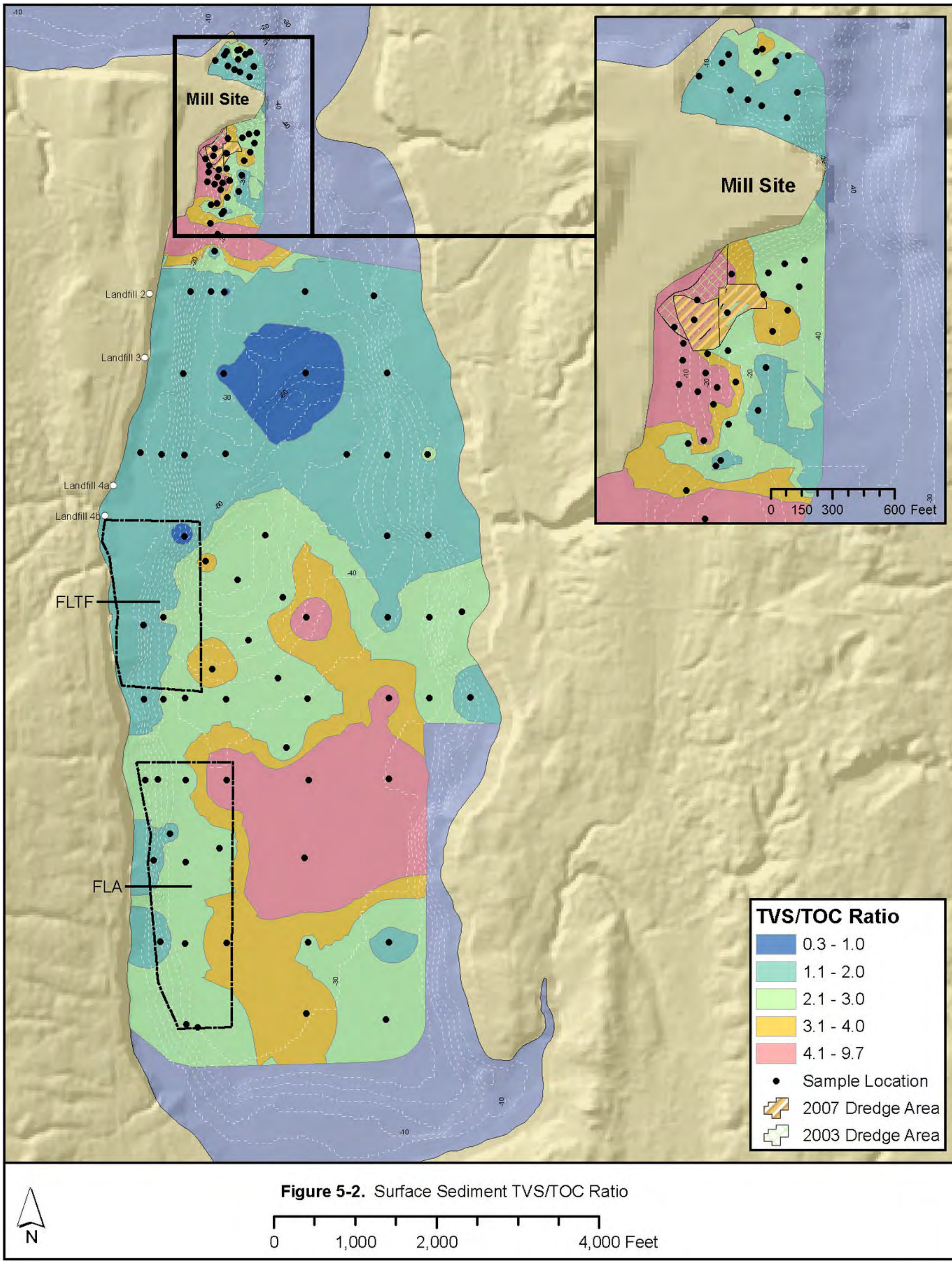


Figure 5-2. Surface Sediment TVS/TOC Ratio

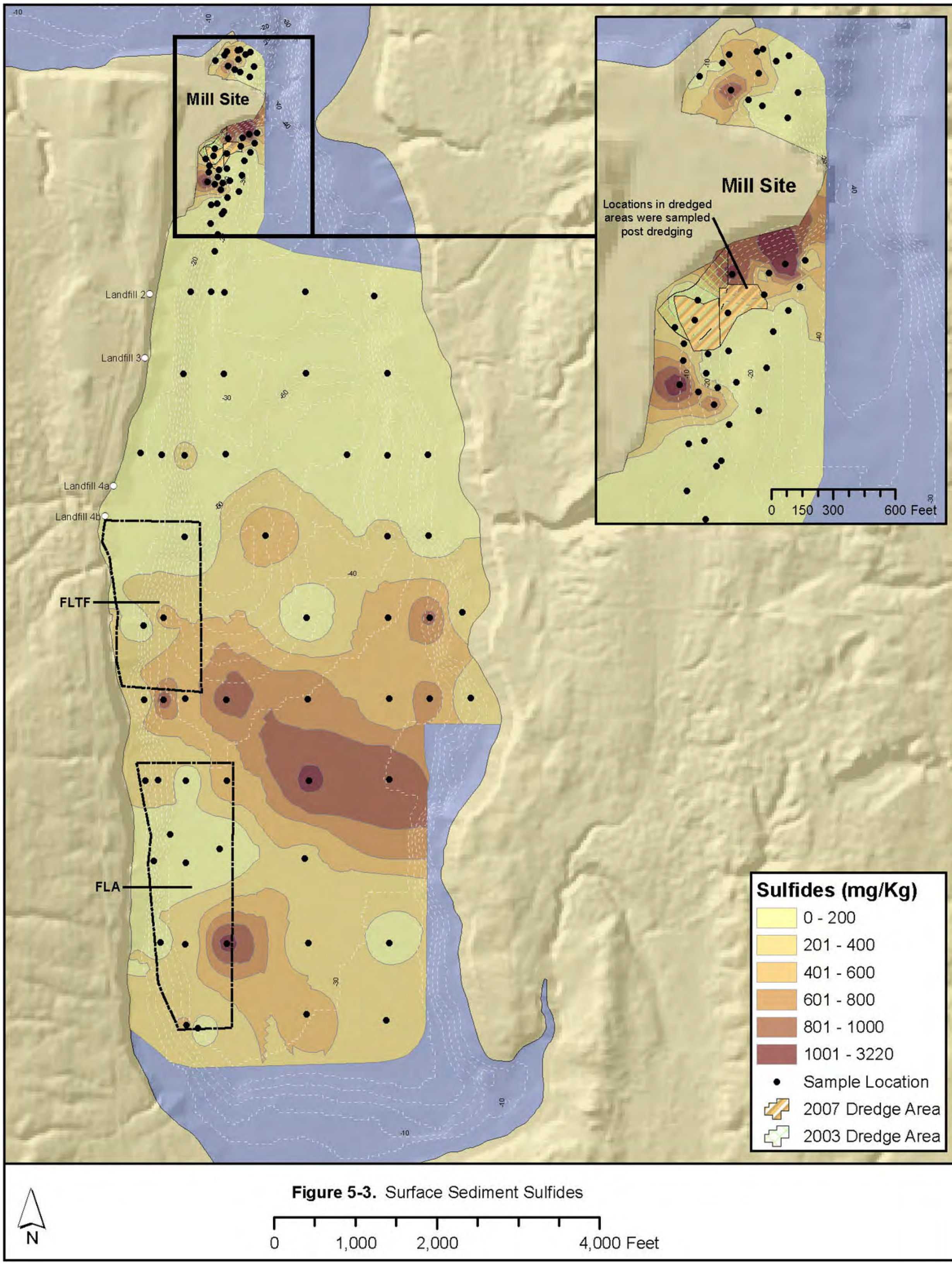


Figure 5-3. Surface Sediment Sulfides

Porewater sulfides are shown in Figure 5-4, and are generally considered the more bioavailable fraction of sulfides. In general, high concentrations of porewater sulfides up to 93.9 mg/L are located in the northern embayment near the former mill site and along the shoreline south of the former mill site. Porewater sulfides in surface sediments in these areas may be related to tidal pumping through wood waste deposits that continually generates sulfides through microbial breakdown processes (Anchor 2010). The elevated sulfide concentrations in the south end of the bay may be due to microbial breakdown of naturally occurring organic matter because they are not colocated with other wood waste indicators.

Ammonia concentrations in the bay ranged from 2.75–53.6 mg/kg, with the highest concentrations in the south-central portion of the bay and near the eastern boundary of the FLA. Stations near the former mill ranged up to 105 mg/kg. Intertidal ammonia concentrations were generally quite low, ranging from 3.3–22.8 mg/kg. Elevated ammonia concentrations are also indicative of organic-rich, anaerobic sediment and may be associated with low oxygen due to degradation of wood waste, even though wood itself contains very little nitrogen. While these levels of ammonia are not believed to be high enough to cause toxicity alone, samples containing the highest ammonia concentrations are generally colocated with sulfides, visual wood waste presence, and higher TVS/TOC (Figure 5-5).

5.3 Fatty and Resin Acids

Both fatty acids (oleic and linoleic) and resin acids (abietic acids, pimaric acids, and palustric acid) were analyzed (Table 5-2). These two classes of compounds help identify the presence of wood waste, and resin acids have been associated with toxicity in runoff from log sort yards and in wood waste deposits. The distribution of resin acids in subtidal sediment samples is shown in Figure 5-6. These compounds were not analyzed in intertidal sediments.

Oleic acid was detected in every sample at concentrations ranging from 370–8,400 µg/kg. Linoleic acid was detected in 28 of 51 samples analyzed at concentrations ranging from 110–830 µg/kg. Resin acids were detected in 18 of 51 samples analyzed. Total detected resin acid concentrations ranged from 110–4,880 µg/kg. Higher concentrations of fatty acids and resin acids appeared to be somewhat correlated, although fatty acids were more widely distributed throughout the bay. The highest concentrations of oleic and linoleic acid were found in samples collected from the FLTF, immediately north of the FTLF, and east of the FTLF throughout the width of the bay to the opposite shore. The highest concentrations of resin acids were found in the same locations.

Oleic and linoleic acids also naturally occur in blue-green algae (Ikawa 2004), although typical concentration ranges were not reported. Douglas Fir also contains oleic and linoleic acid (Foster et al. 1980). Reported fatty acid concentrations in Douglas Fir are approximately 100 mg/kg based on analysis of the ether-extractable fraction of wood, with oleic acid comprising 20–30% of the total and linoleic acid comprising 6–10% of the total fatty acids.

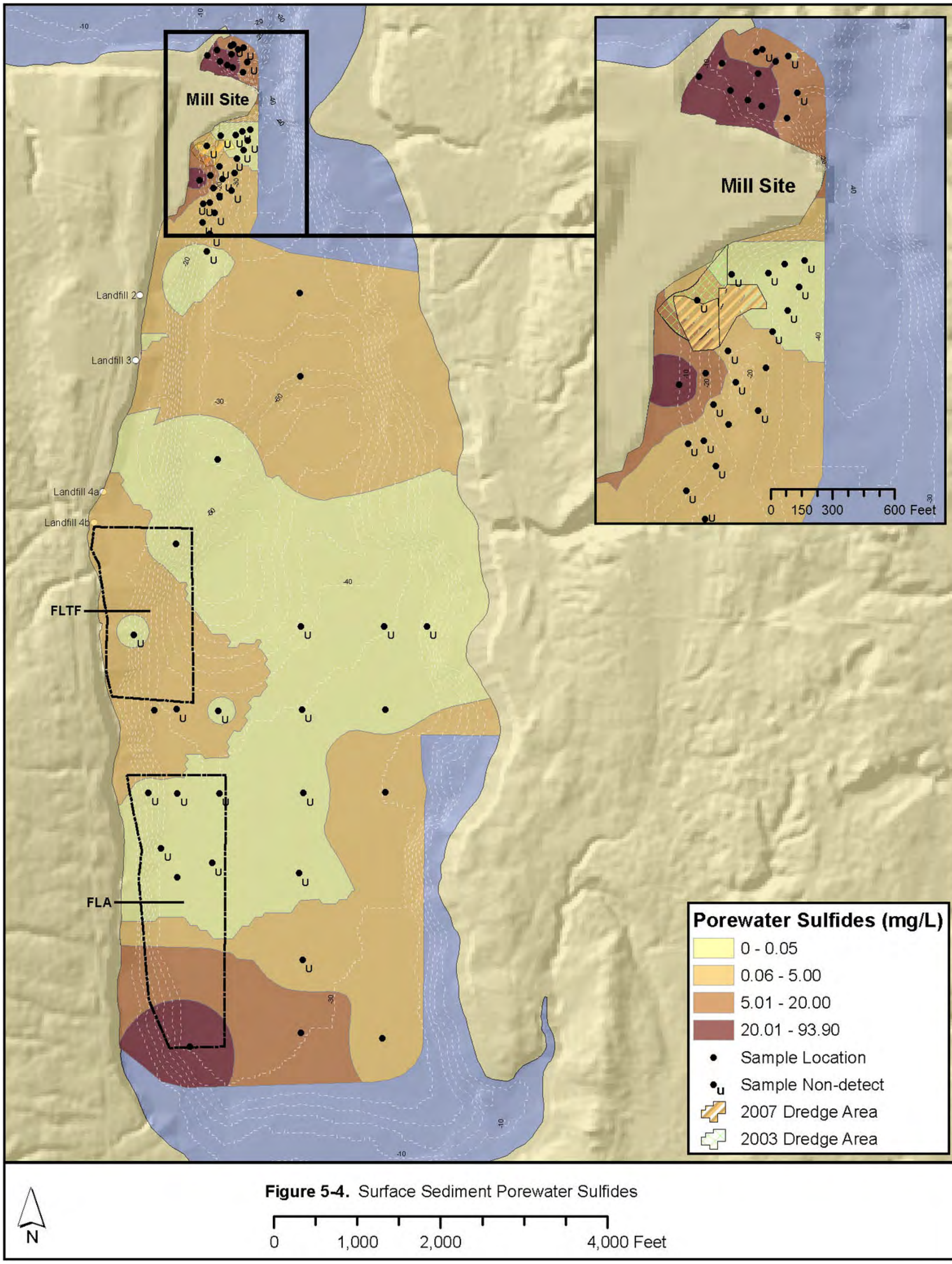


Figure 5-4. Surface Sediment Porewater Sulfides

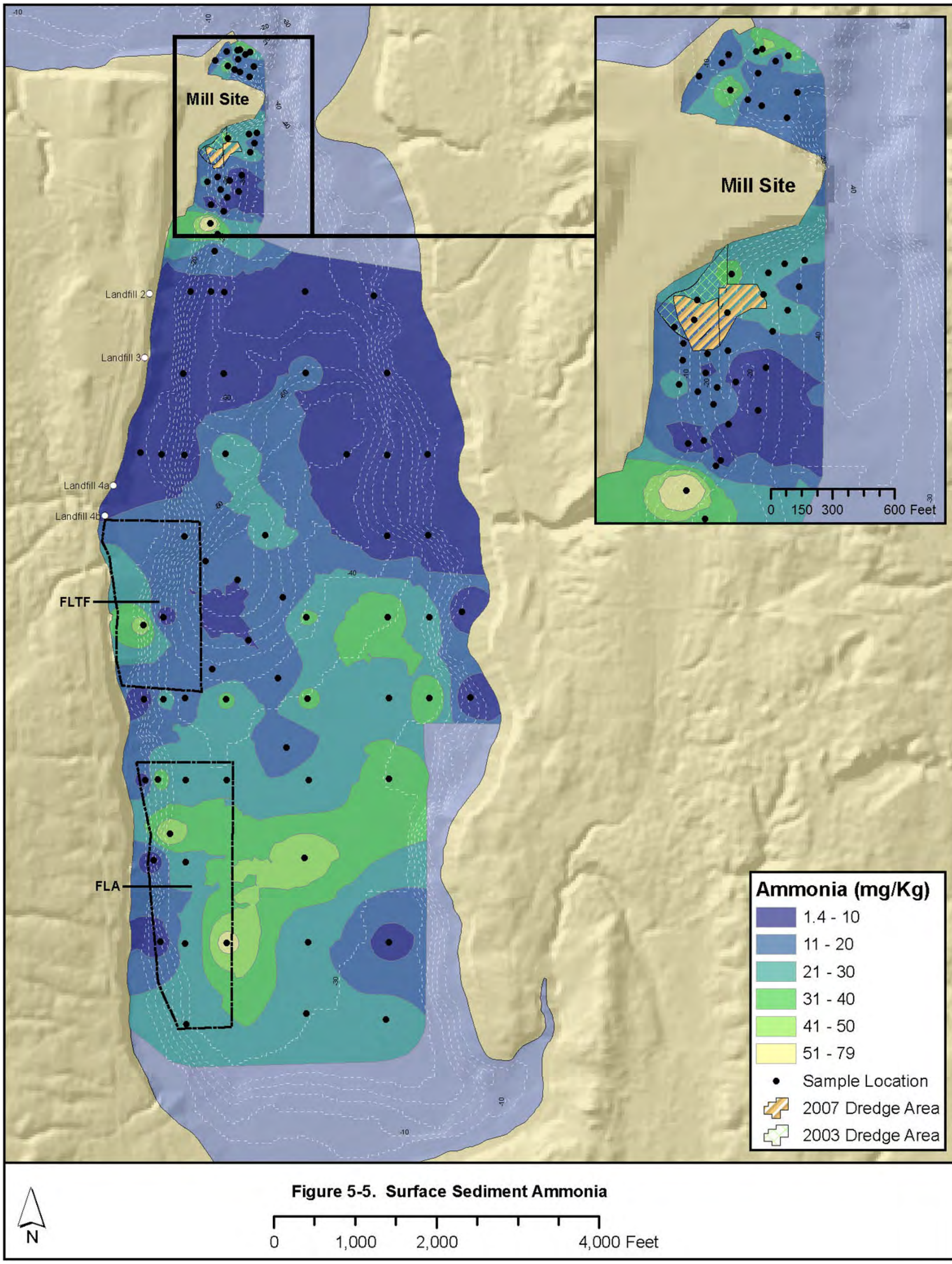


Figure 5-5. Surface Sediment Ammonia

Table 5-2. Summary of Sediment Fatty and Resin Acid Results

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Subtidal Samples												
Resin Acids in µg/kg												
9,10-Dichlorostearic Acid	49	0	95	100	97.8	99	2	0	97	99	98	98.8
Abietic Acid	56	14	95	4400	280	530	8	3	84	320	146	306
Dehydroabietic Acid	56	18	86	950	152	275	8	2	62	210	98.3	179
Isopimaric Acid	49	1	95	160	99.1	99	2	0	97	99	98	98.8
Linoleic Acid	49	28	96	830	200	442	2	2	110	170	140	164
Neoabietic Acid	29	0	96	100	98.2	99.2	2	0	97	99	98	98.8
Oleic Acid	49	49	370	8400	2150	5220	2	2	1600	4600	3100	4300
Palustric Acid	49	0	95	100	97.8	99	2	0	97	99	98	98.8
Pimaric Acid	56	0	95	100	98	99	8	0	47	99	60.3	97.6
Sandaracopimaric Acid	49	0	95	100	97.8	99	2	0	97	99	98	98.8

Non-detects included in descriptive statistics.

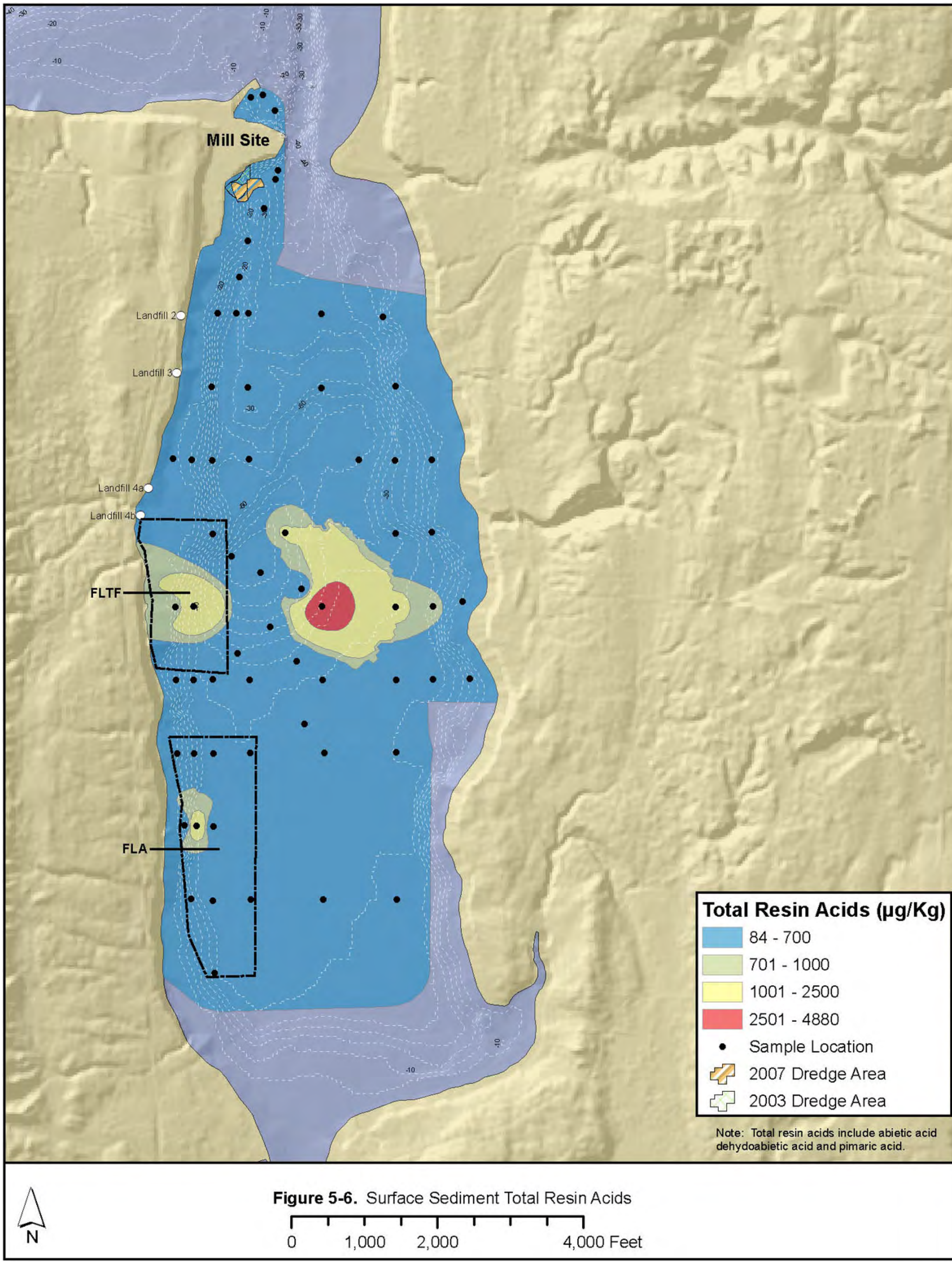


Figure 5-6. Surface Sediment Total Resin Acids

Resin acid concentrations in Douglas Fir are approximately 2,000–2,700 mg/kg based on analysis of the ether-extractable fraction of wood, with concentrations decreasing in the following order: isopimaric > palustric > abietic > neoabietic > dehydroabietic acids. Palustric acid and isopimaric acid each constitute about 20–30% of the total resin acids in Douglas Fir.

Based on the distribution of fatty and resin acids combined with SPI images and visual observations of sediment samples, resin acids appear to be a good indicator of wood waste. Fatty acids may reflect the presence of both wood waste and naturally occurring algae.

5.4 Total Metals

All metals concentrations were below applicable SQS screening criteria (Table 5-3). Therefore, the metals selected for discussion below were evaluated due to their potential human health effects (see Section 8). Concentrations on the figures are generally shown relative to natural background concentrations; in addition, undetected values are shown in blue with a "u" symbol. Samples with the highest metals concentrations were generally from the southern half of the bay; the higher metals concentrations may be associated with the fine-grained silt and clay or ephemeral stream inputs present in this area. For most metals, concentrations in intertidal samples were lower than in subtidal sediments, likely due to the more coarse-grained nature of the sediments.

Arsenic was detected in 6 of 44 subtidal samples in the bay, with detected concentrations in subtidal samples ranging from 2.25–20 mg/kg. Near the former mill, concentrations were similar, ranging from 2.6–25.4 mg/kg. In intertidal samples, arsenic was detected in all samples at lower levels of 0.92–6.1 mg/kg (Figure 5-7). The detection limits in the existing studies were above these concentrations, and thus lower detection limits were obtained during the 2011 NewFields RI to obtain a better sense of the actual concentrations for human health evaluations and natural background comparisons.

Cadmium was detected in 39 of 44 subtidal samples in the bay, with detected concentrations ranging from 0.33.1 mg/kg, with concentrations similar in the bay and near the former mill site. Cadmium was detected in 6 of 15 intertidal samples at concentrations of 0.1–1.1 mg/kg. Cadmium concentrations tend to be highest in the southern portion of the bay where sediments are very fine-grained (Figure 5-8).

Copper was detected in all samples, ranging from 3.4–40.2 mg/kg in the bay, 8.4–52.7 near the former mill, and 5.9–48.2 in intertidal sediments (Figure 5-9). Like cadmium, higher concentrations tend to be found in the southern half of the bay.

Mercury was detected in 25 of 44 subtidal samples, with detected concentrations ranging from 0.02–0.13 mg/kg in the bay and 0.014–0.07 near the former mill. Mercury was detected in 5 of 15 intertidal samples at concentrations of 0.03–0.08 mg/kg (Figure 5-10). Like the other metals, mercury tends to be slightly elevated in the fine-grained central portion of the bay.

Table 5-3. Summary of Sediment Metals Results

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Subtidal Samples												
Metals in mg/kg												
Arsenic	52	10	2.25	20	8.89	10	15	11	2.6	25.4	6.41	10.2
Cadmium	52	48	0.1	3.1	1.32	2.3	15	14	0.2	2.6	0.947	2.07
Chromium	52	52	7.3	53	34.6	49	12	12	15	88	27.6	29.7
Copper	52	52	3.4	40.2	24.8	38.2	15	15	8.4	52.7	22.3	38.2
Lead	52	45	2	15	8.49	13.9	15	15	3	37.4	11.1	28.1
Silver	52	0	0.1	1	0.612	0.9	12	0	0.1	0.6	0.35	0.5
Zinc	52	52	16	94	62.2	90	15	15	29	109.85	54.3	93.4
Mercury	52	32	0.02	0.13	0.0757	0.1	12	1	0.014	0.07	0.0338	0.059
Intertidal Samples												
Metals in mg/kg												
Arsenic	15	15	1.5	6.1	2.88	4.58	10	10	0.92	4.1	2.48	3.92
Cadmium	15	6	0.1	0.74	0.196	0.3	10	5	0.10	1.1	0.376	1.1
Chromium	15	15	15	40	26.2	36.3	10	10	9.00	31.4	20.7	25.9
Copper	15	15	5.9	48.2	13.6	20.2	10	10	15.00	41.6	26.1	36.6
Lead	15	9	2	31	6.63	13.5	10	10	3.70	24	10.8	19.5
Silver	15	0	0.072	0.9	0.445	0.72	10	0	0.06	0.9	0.337	0.9
Zinc	15	15	23	91.5	38.5	57.8	10	10	36.00	175	66.1	159
Mercury	15	5	0.014	0.08	0.0323	0.052	10	2	0.01	0.03	0.019	0.03

Non-detects included in descriptive statistics.

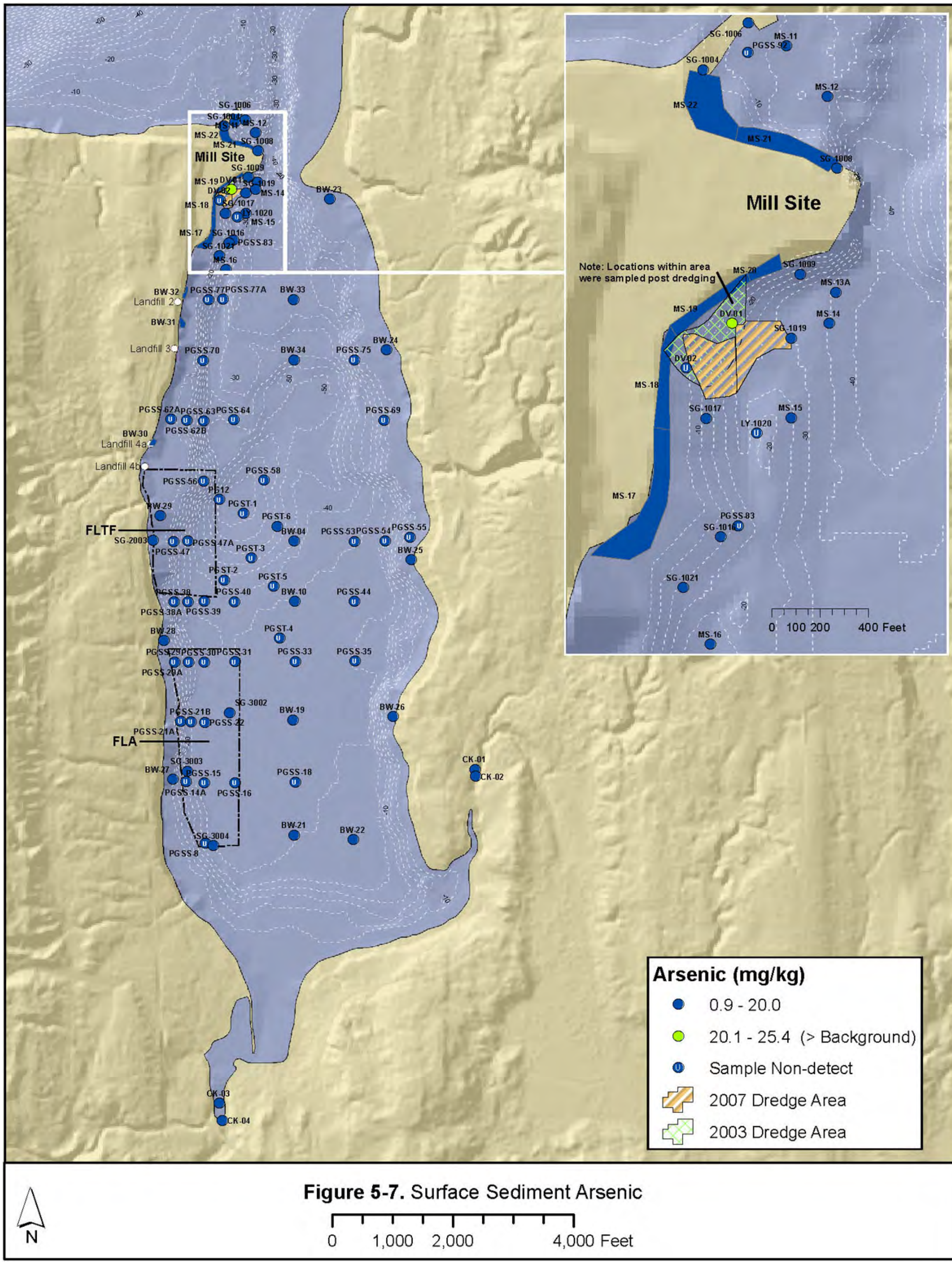


Figure 5-7. Surface Sediment Arsenic

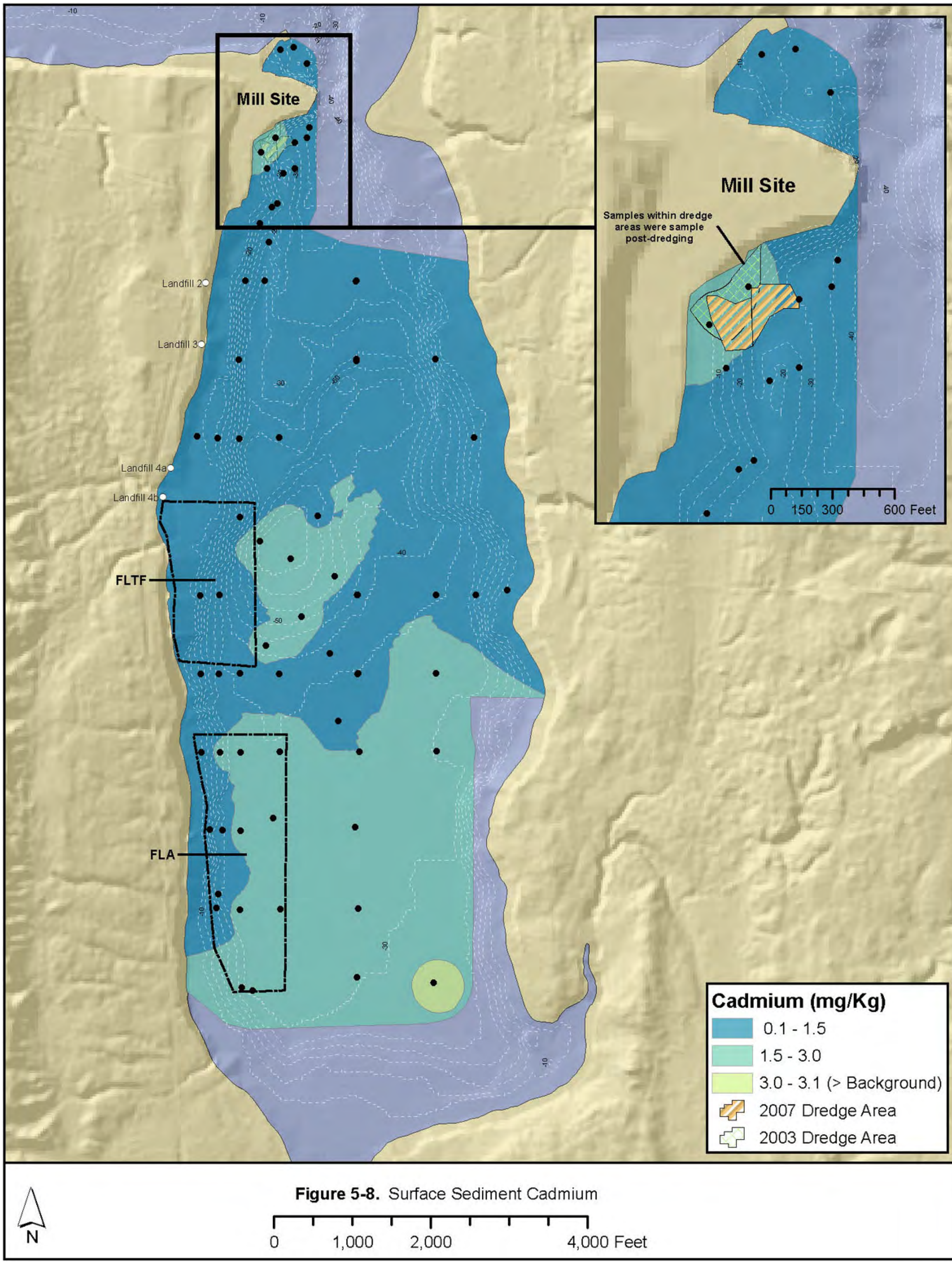


Figure 5-8. Surface Sediment Cadmium

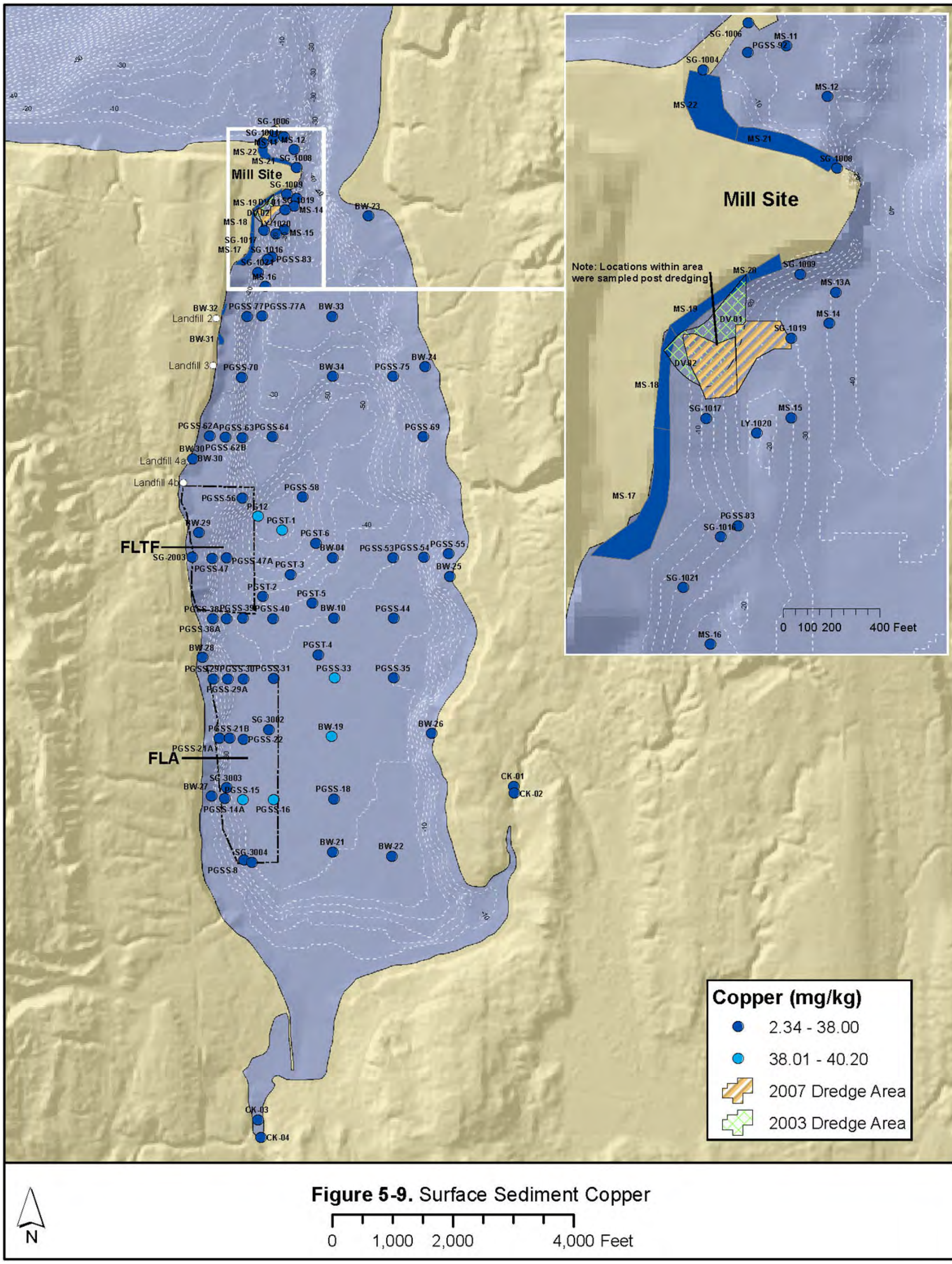


Figure 5-9. Surface Sediment Copper

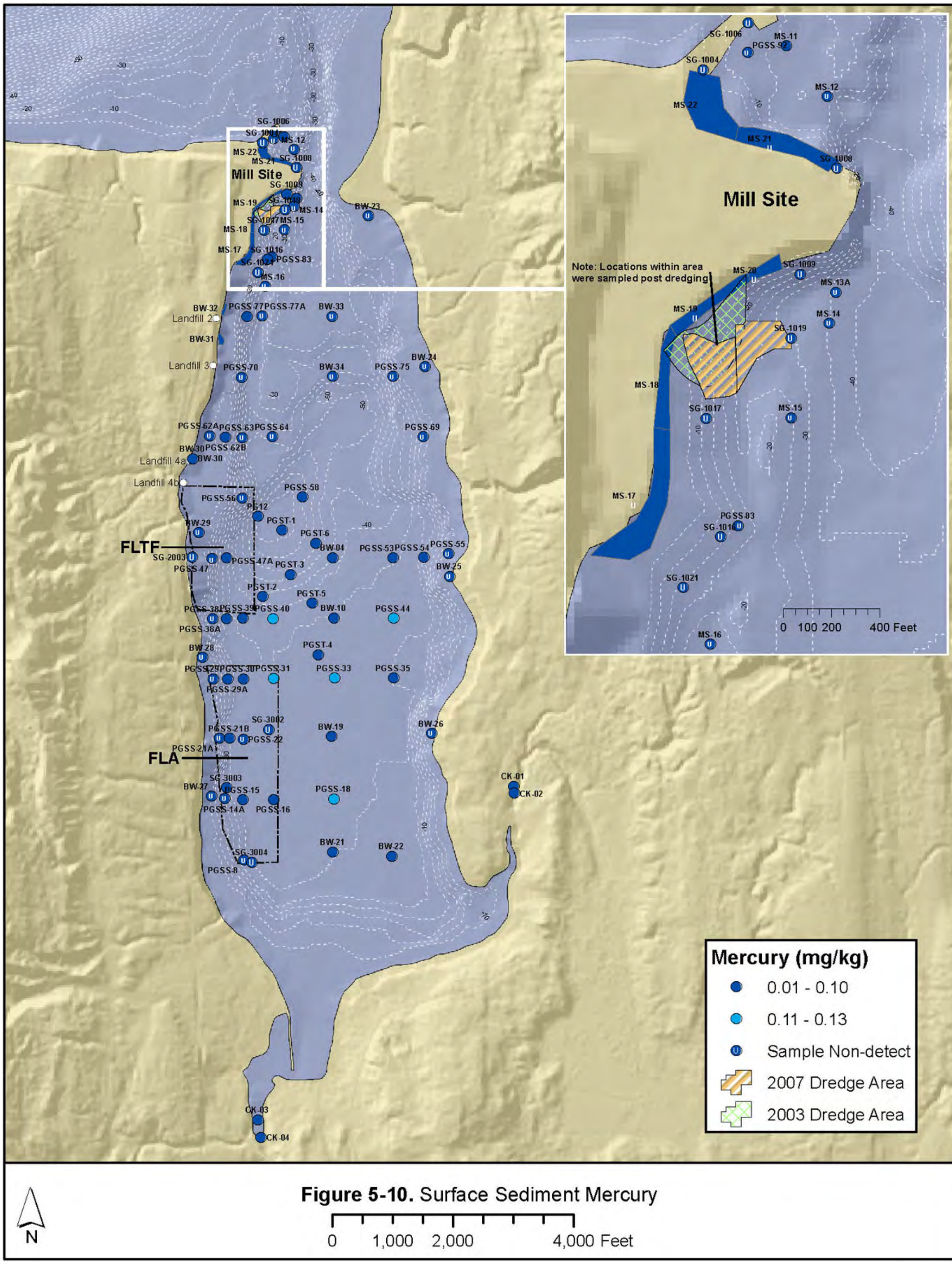


Figure 5-10. Surface Sediment Mercury

The relationship between metals concentrations and percent fines was further investigated to confirm the observed patterns, using the most recent data from both the subtidal and intertidal zones (n = 54; New Fields 2011 and Hart Crowser 2010). Scatterplots (Figures 5-11, 5-12) were used to visualize the data and assist in outlier identification. On these scatterplots, data values below detection are shown as dashed lines between 0 and the detection limit. The best fit regression lines are the ordinary least squares regression for endpoints with all data values above detection limits (i.e., chromium, copper, and zinc), or the Akritas-Theil-Sen nonparametric regression for endpoints with some values below detection (i.e., arsenic, cadmium, and mercury). Pearson's correlation coefficient was used to identify the strength and direction of the linear correlations for endpoints with all values above detection limits; otherwise Kendall's tau was used to describe the level of rank correlation.

The correlations (Table 5-4) were significant for all of the metals investigated (cadmium, chromium, copper, mercury, and zinc, $p < 0.05$) except for arsenic (p=0.11). Arsenic was detected in only half the observations and included some very high detection limits. Even with the uncertainty of the non-detects, the rank correlation was still very strong (p=0.11). The relationships between metals and fines appeared to be similar for mill area and bay samples for most of the metals investigated (Figure 5-11 A–D), with the exception of copper and zinc. The mill area stations had a small range of percent fines values (0–24%), which provided limited information for the correlation analysis. When the relationship appeared to be somewhat different for the mill area stations, correlations were conducted for two groups: all samples, and samples excluding stations in the mill area.

Table 5-4. Correlation Coefficients between Metals and Fines

Percent Fines vs.	Detection Frequency for the Metal	Correlation Test	Correlation Coefficient (p-value)	Outlier Samples
Arsenic	28/54	Kendall's tau	0.143 (p = 0.11)	None
Cadmium	41/54	Kendall's tau	0.776 (p = 0)	None
Chromium	54/54	Pearson's r	0.731 (p = 0)	Subtidal sample MS-12
Copper	54/54	Pearson's r	Bay: 0.846 (p = 0) Subtidal: 0.931 (p = 0) All samples: 0.502 (p = 0)	Intertidal samples MS-20, MS-21, MS-22, and BW-31
Mercury	25/54	Kendall's tau	0.521 (p = 0)	None
Zinc	54/54	Pearson's r	0.516 (p = 0)	Intertidal samples MS-19, MS-20

There were a number of samples with low fines and higher copper concentrations (Figure 5-12A). These were primarily mill area stations, but not exclusively. Many of the mill area stations did follow the general positive correlation pattern of increasing copper with increasing percent fines. A second plot of the copper data was prepared distinguishing between subtidal and intertidal stations (Figure 5-12B). The four unusual samples are all intertidal, but many more intertidal samples follow the general positive correlation pattern. The four intertidal stations with low fines (3% or less) and higher copper concentrations are MS-21 (34 mg/kg copper), MS-22 (34 mg/kg copper), MS-20 (42 mg/kg copper), and BW-31

(48 mg/kg copper). The best relationship appears to be among the subtidal samples, with the intertidal areas exhibiting substantial variability in copper concentrations within the low % fines range.

Chromium (Figure 5-11C) and zinc (Figure 5-12C) also had one or two stations that appeared to be outliers to the general patterns for these metals. These were samples with very low fines and very high concentrations of these two metals. For chromium, the outlier was subtidal sample MS-12 from the mill area (6% fines and 88 mg/kg chromium). For zinc, the outliers were intertidal samples MS-19 and MS-20 from the mill area (3% fines and 175 and 157 mg/kg zinc, respectively). Debris was observed along the northwestern shoreline during field sampling, and these results suggest that this debris and related sources (e.g., landfills) may be contributing to concentrations observed in intertidal samples from this area.

Overall, the patterns and correlations observed suggest that metals concentrations in the bay are heavily influenced by fine-grained sediments, binding to clay and being transported to the very high fines (>80%) areas of the bay to the south. Several individual samples appear to be exceptions to this rule, generally in intertidal areas near the former mill.

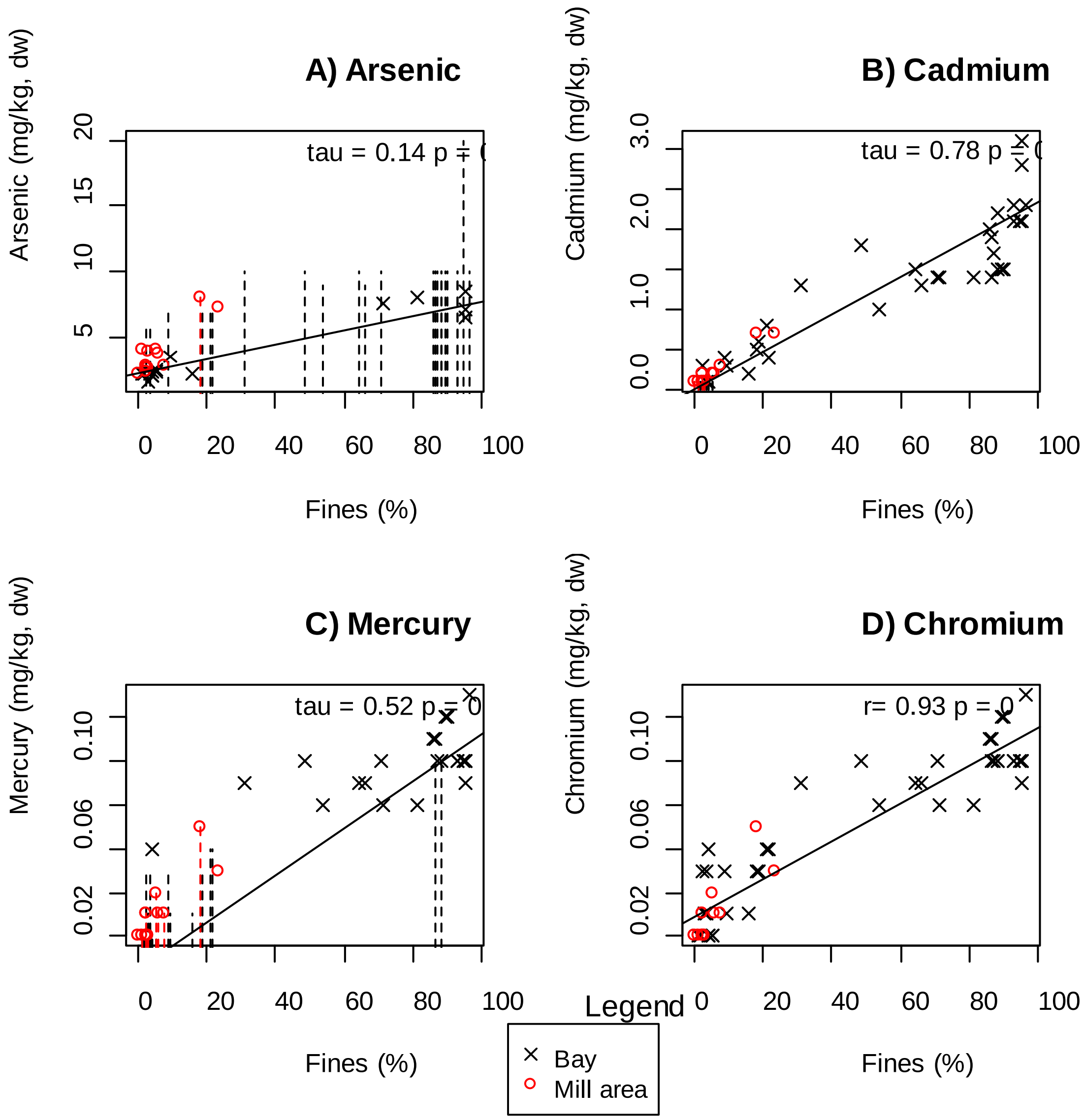


Figure 5-11. Correlations between Arsenic, Cadmium, Chromium, and Mercury and the Fine-Grained Sediment Fraction.

The best-fit regression line, the correlation coefficient (Kendall's tau or Pearson's r), and its significance level (p) are shown on each plot. Values below detection are shown as dashed lines between 0 and the detection limit.

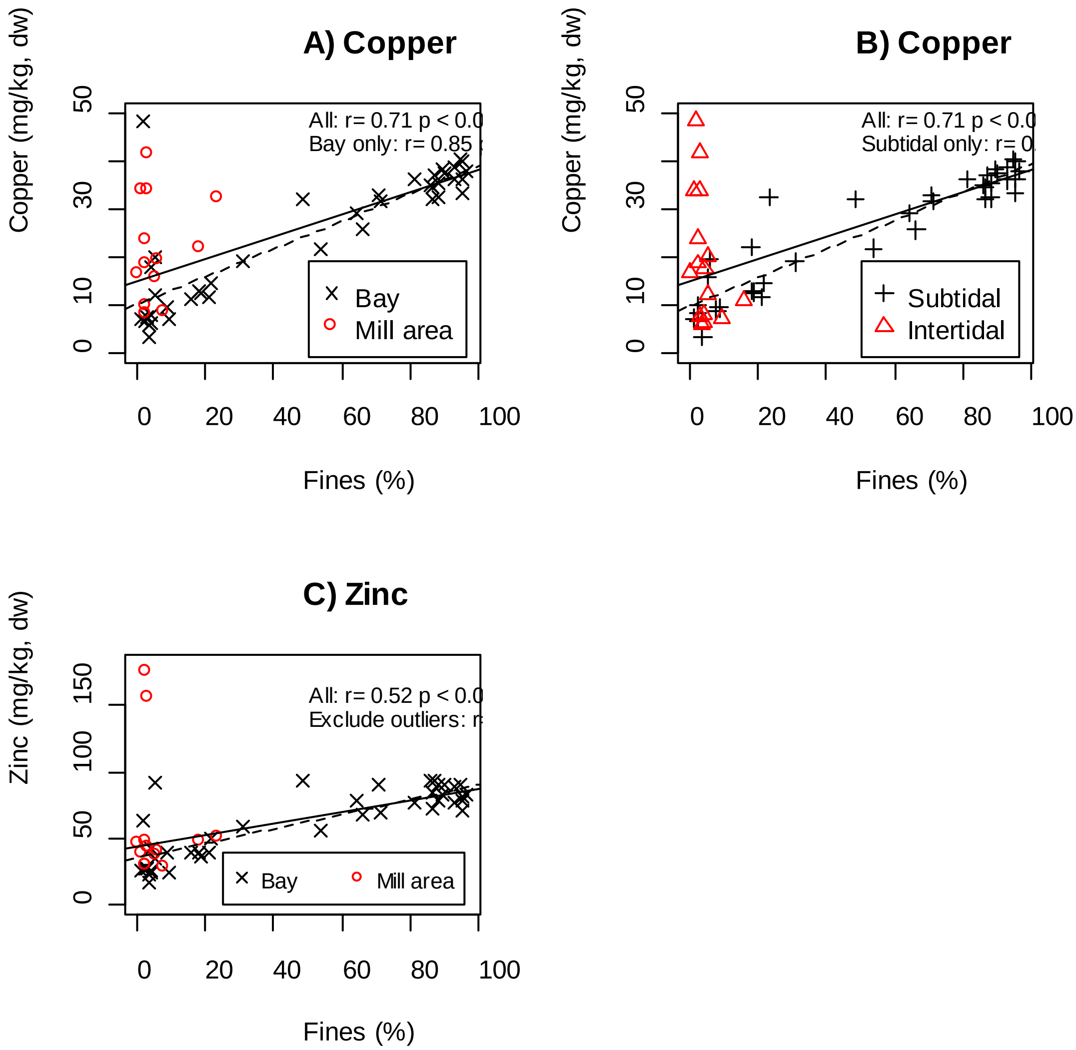


Figure 5-12. Correlations between Copper and Zinc Concentrations and the Fine-Grained Sediment Fraction.

The best-fit regression line, the Pearson correlation coefficient (r), and its significance level (p) are shown on each plot. The solid line shows the best-fit regression line for all of the data; the dashed line shows the best-fit regression line for the bay-only samples or the subtidal-only samples.

5.5 Semivolatile Organic Compounds

Except for locations PGSS-8, PGSS-20, PGSS-21B, PGSS-22, PGSS-30, PGSS-31, PGSS-44, PGSS-75, PGSS-80, and BW-22S, subtidal sediment TOC concentrations were within the 0.5–3.5% range for organic carbon (OC) normalization of nonpolar organics. However, most of the intertidal samples were well outside this range (TOC too low around the bay and too high in creek samples), and should not be OC normalized. Thus, both dry weight and OC-normalized values are presented for SMS chemicals with OC-normalized criteria.

Other than phenol, none of these analytes exceeded SMS OC normalized criteria or apparent effects threshold dry-weight screening values for nonpolar organic compounds. No phthalates or chlorinated benzenes were detected in any of the samples. Of the detected SVOCs, carcinogenic PAHs (cPAHs) are considered contaminants of concern for human health (see Section 8) and are discussed in greater detail below.

5.5.1 Polynuclear Aromatic Hydrocarbons

PAHs were detected in all but six subtidal samples analyzed, with cPAH toxic equivalency quotient (TEQs) ranging from 5.2–94.8 (μg/kg) in the bay and up to 280 μg/kg near the mill (Tables 5-5 and 5-6). Lower levels were found in intertidal samples, ranging from 1.51–47.9 μg/kg in the bay and up to 340 μg/kg near the mill. In general, samples with the highest concentrations of cPAHs above natural background were near the mill (both north and south) and in the central and southern bay (Figure 5-13).

While cPAH concentrations were often above natural background, the range of concentrations measured at Port Gamble were comparable to or lower than data from other bay-wide studies within Puget Sound. In addition to Port Gamble, sediment investigations have been conducted at Fidalgo Bay, Budd Inlet, Port Angeles, and Port Gardner as part of the Puget Sound Initiative. These bays represent varying degrees of urban density and proportion of historic versus current industrial activity. The range of subtidal surface sediment cPAH concentrations from these investigations is presented in Figure 5-14. For reference, data from the highly urban/industrial Lower Duwamish Waterway (LDW) and the Port Gamble natural background data set were also included. All data were available in Ecology's Environmental Information Management (EIM).

All of the data presented in Figure 5-14 were normalized to OC content to minimize the differences in physical characteristics between the investigations. The OC-normalization also allows a more meaningful comparison with respect to availability of the cPAHs, since uptake from sediments is mediated by the organic fraction. The upper and lower bars represent the 90th and 10th percentiles, while the upper and lower bounds of the box represent the 75th and 25th percentiles, respectively. As discussed in Section 9.1, Port Gamble Bay sediments were above the natural background for cPAHs. The 90th percentile at Port Gamble Bay was the lowest of all of the investigations, indicating that Port Gamble Bay does not have sediments in the higher concentration ranges measured elsewhere in Puget Sound. The majority of the sediment samples from Port Gamble Bay, those under the 75th percentile, were similar to Fidalgo Bay, but lower than the more urban Port Gardner, Port Angeles, and Budd Inlet.

Table 5-5. Summary of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Results – Dry Weight

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
PAHs in µg/kg												
Naphthalene	51	31	11	1600	196	390	15	8	3.8	585	132	396
Acenaphthylene	51	28	6	450	61.4	100	15	7	1.4	47	25.5	40.5
Acenaphthene	51	28	3.1	120	26.8	45	15	8	6.9	151.5	36.6	58
Fluorene	51	28	2.2	81	24.6	40	15	8	6.2	161	36.9	59.8
Phenanthrene	51	36	11	630	98.5	210	15	15	19	410	156	316
Anthracene	51	31	3.3	130	31.3	48	15	12	8.5	120	51.5	103
2-Methylnaphthalene	51	28	2.7	92	23.9	40	15	7	2	112	28.4	49.8
1-Methylnaphthalene	48	28	2.6	78	20.8	33.4	8	6	3.1	30	16.8	27.6
Total LPAHs	51	37	11	3171	398	765	15	15	19	1617	392	872
Fluoranthene	51	42	9.7	560	110	250	15	15	30	590	280	546
Pyrene	51	40	12	550	111	250	15	15	32	430	205	392
Benzo(a)anthracene	51	35	4	71	28.3	47	15	15	12	200	91.3	189
Chrysene	51	39	5.2	91	36.3	62	15	15	12	570	181	368
Benzo(b)fluoranthene	41	29	4.4	58	29	48	10	9	11	255	93.9	251
Benzo(k)fluoranthene	41	29	2.4	57	19.2	26	10	9	6	140	53.6	136
Total Benzofluoranthenes	48	37	6.8	130	47.2	77.2	10	9	17	390	146	378
Benzo(a)pyrene	51	35	4	69	30.6	56	15	15	9.5	210	80.5	184
Indeno(1,2,3-cd)pyrene	51	32	2.5	47	19.7	39	15	12	3.6	92	40.3	83.2
Dibenz(a,h)anthracene	51	20	2.4	47	13.3	20	15	5	2.5	39	18.8	32.8
Benzo(g,h,i)perylene	51	33	2.9	70	27	47	15	11	5.4	95.5	38.2	83.4
Total HPAHs	51	42	9.7	1588.7	359	830	15	15	100	2268	1000	1940
cPAH TEQ	51	*	5.2	94.8	35.8	71.9	15	*	13.4	279	106	254
Intertidal Samples												
PAHs in µg/kg												
Naphthalene	15	12	3.3	300	46.1	119	10	2	3.9	63	19.6	22.5
Acenaphthylene	15	6	1.3	54	9.86	28.8	10	3	1.3	18	10	18
Acenaphthene	15	5	1.2	21	4.93	14	10	5	1.2	18	11.4	18
Fluorene	15	6	1.3	21	5.26	13.8	10	6	1.3	54	15.5	21.6
Phenanthrene	15	14	1.9	160	32.7	84.4	10	8	12.0	200	71.3	164
Anthracene	15	7	2.1	26	7.63	20.2	10	7	4.3	250	40.1	70
2-Methylnaphthalene	15	6	1.9	21	5.15	11.5	10	4	1.9	18	9.21	18
1-Methylnaphthalene	14	5	1.5	18	4	10.2	6	4	1.5	8.8	5.33	8
Total LPAHs	15	15	6.1	571	92.7	265	10	8	16.0	504	131	275
Fluoranthene	15	14	3	150	44.9	128	10	9	16.0	760	171	391
Pyrene	15	14	2.6	160	42.5	112	10	9	16.0	430	106	205
Benzo(a)anthracene	15	10	1.8	56	10.4	18.8	10	9	16.0	200	56.1	155
Chrysene	15	10	2.2	110	15.9	21.4	10	9	16.0	590	135	419

Table 5-5. Summary of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Results – Dry Weight

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Benzo(b)fluoranthene	14	9	1.9	17	7.58	16.7	6	6	18.0	420	101	240
Benzo(k)fluoranthene	14	8	2.1	8.4	4.24	7.82	6	6	8.5	200	47.3	115
Total Benzofluoranthenes	14	9	2.1	24.4	10.8	24.1	6	6	26.5	620	148	355
Benzo(a)pyrene	15	9	2.1	39	9.86	19.8	10	9	14.0	240	56.7	132
Indeno(1,2,3-cd)pyrene	15	7	2.6	21	5.43	10.6	10	7	4.6	91	26	64.9
Dibenz(a,h)anthracene	15	0	2.5	21	3.79	2.66	10	4	2.5	33	12.1	19.5
Benzo(g,h,i)perylene	15	9	2.4	22	7.68	21	10	7	5.0	92	24.4	55.1
Total HPAHs	15	14	3	455	139	380	10	9	16.0	3056	653	1490
cPAH TEQ	15	*	1.51	47.9	12.2	25.0	10	*	10.5	340	74.8	166

Non-detects included in descriptive statistics.

* TEQs shown in this table used the method described in Section 8.2.4. Using this method, all final estimated TEQ values are treated as detected; therefore, summary statistics can be calculated on the estimated TEQs even if most or all of the component congeners were undetected.

Table 5-6. Summary of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Results – Organic Carbon Normalized

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
PAHs in mg/kg OC												
Naphthalene	51	31	0.38	42	6.62	15	15	8	0.4	8.9	3.14	7.32
Acenaphthylene	51	28	0.18	12	2.38	4.2	15	7	0.16	2	0.796	1.62
Acenaphthene	51	28	0.091	7	1.31	2.2	15	8	0.2	3.5	1.08	1.78
Fluorene	51	28	0.1	7	1.24	2.1	15	8	0.23	3	1.03	1.82
Phenanthrene	51	36	0.32	16	3.71	7.1	15	15	0.84	16	4.99	12.3
Anthracene	51	31	0.16	7	1.47	2.6	15	12	0.31	11	1.87	2.94
2-Methylnaphthalene	51	28	0.094	7	1.21	2.2	15	7	0.19	1.9	0.701	1.12
1-Methylnaphthalene	48	28	0.088	7	1.14	2	8	6	0.49	1.8	0.918	1.26
Total LPAHs	51	37	0.32	82	13.2	33	15	15	1	33	11.1	22
Fluoranthene	51	42	0.71	14	4.21	9.4	15	15	0.94	42	10.3	26.2
Pyrene	51	40	0.71	14	4.23	9.8	15	15	0.74	35	7.85	19.4
Benzo(a)anthracene	51	35	0.24	7	1.4	2	15	15	0.4	7.05	2.53	5.46
Chrysene	51	39	0.32	7	1.7	2.6	15	15	0.4	14.95	5.16	11.5
Benzo(b)fluoranthene	41	29	0.27	7	1.6	2.2	10	9	0.64	10.15	3.18	7.5
Benzo(k)fluoranthene	41	29	0.15	7	1.23	2.2	10	9	0.36	5.25	1.67	3.5
Total Benzofluoranthenes	48	37	0.41	7	2.13	3.33	10	9	0.66	15.65	4.71	10.6
Benzo(a)pyrene	51	35	0.24	7	1.49	2.2	15	15	0.37	8.65	2.32	4.7
Indeno(1,2,3-cd)pyrene	51	32	0.14	7	1.09	2	15	12	0.22	3.25	1.06	1.82
Dibenz(a,h)anthracene	51	20	0.057	7	0.871	2	15	5	0.071	1.9	0.569	1.07

Table 5-6. Summary of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Results – Organic Carbon Normalized

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Benzo(g,h,i)perylene	51	33	0.18	7	1.35	2.2	15	11	0.31	3.95	1.1	1.96
Total HPAHs	51	42	1.1	43	13.2	32	15	15	3.3	120	33.6	89.4
cPAH TEQ	51	*	0.323	4.86	1.58	2.80	15	*	0.472	7.89	2.84	6.79
Intertidal Samples												
PAHs in mg/kg OC												
Naphthalene	15	12	0.24	6.6	2.94	6.32	10	2	0.29	20	4.74	9.74
Acenaphthylene	15	6	0.026	1.8	0.7	1.4	10	3	0.15	20	3.18	7.4
Acenaphthene	15	5	0.016	1.8	0.46	1.01	10	5	0.19	20	3.52	7.4
Fluorene	15	6	0.016	1.8	0.54	1.22	10	6	0.33	20	3.71	7.4
Phenanthrene	15	14	0.12	4.9	2.61	4.36	10	8	1.5	31	10.1	21.1
Anthracene	15	7	0.028	1.8	0.74	1.36	10	7	0.76	20	5.51	17.3
2-Methylnaphthalene	15	6	0.037	1.8	0.54	1.1	10	4	0.079	20	3.24	7.4
1-Methylnaphthalene	14	5	0.02	0.64	0.38	0.627	6	4	0.12	1.5	0.78	1.35
Total LPAHs	15	15	0.12	16	6.6	13.2	10	8	1.5	41	15.8	34.7
Fluoranthene	15	14	0.11	13	4.27	8.44	10	9	5.7	33	17.2	25.8
Pyrene	15	14	0.09	8.3	3.88	7.76	10	9	4.3	22	12.7	20.2
Benzo(a)anthracene	15	10	0.023	4.7	1.2	3.34	10	9	2.2	20	7.33	11
Chrysene	15	10	0.028	9.2	1.75	3.7	10	9	5	27	12.1	20.7
Benzo(b)fluoranthene	14	9	0.039	2.7	0.95	2.15	6	6	4	9.3	7.33	9.1
Benzo(k)fluoranthene	14	8	0.027	1.5	0.59	1.24	6	6	1.9	4.2	3.37	4.2
Total Benzofluoranthenes	14	9	0.042	4.1	1.36	3.44	6	6	5.8	13	10.6	13
Benzo(a)pyrene	15	9	0.027	3.3	1.14	2.82	10	9	2.2	20	7.07	11
Indeno(1,2,3-cd)pyrene	15	7	0.034	1.8	0.65	1.16	10	7	1	20	4.47	7.4
Dibenz(a,h)anthracene	15	0	0.032	1.8	0.5	0.872	10	4	0.43	20	3.32	7.4
Benzo(g,h,i)perylene	15	9	0.029	1.8	0.82	1.44	10	7	0.42	20	4.46	7.4
Total HPAHs	15	14	0.35	38	13.6	31	10	9	20	100	58.8	99.1
cPAH TEQ	14	*	0.00587	0.197	0.0548	0.116	6	*	0.0143	0.0572	0.0408	0.0569

Non-detects included in descriptive statistics.

* TEQs shown in this table used the method described in Section 8.2.4. Using this method, all final estimated TEQ values are treated as detected; therefore, summary statistics can be calculated on the estimated TEQs even if most or all of the component congeners were undetected.

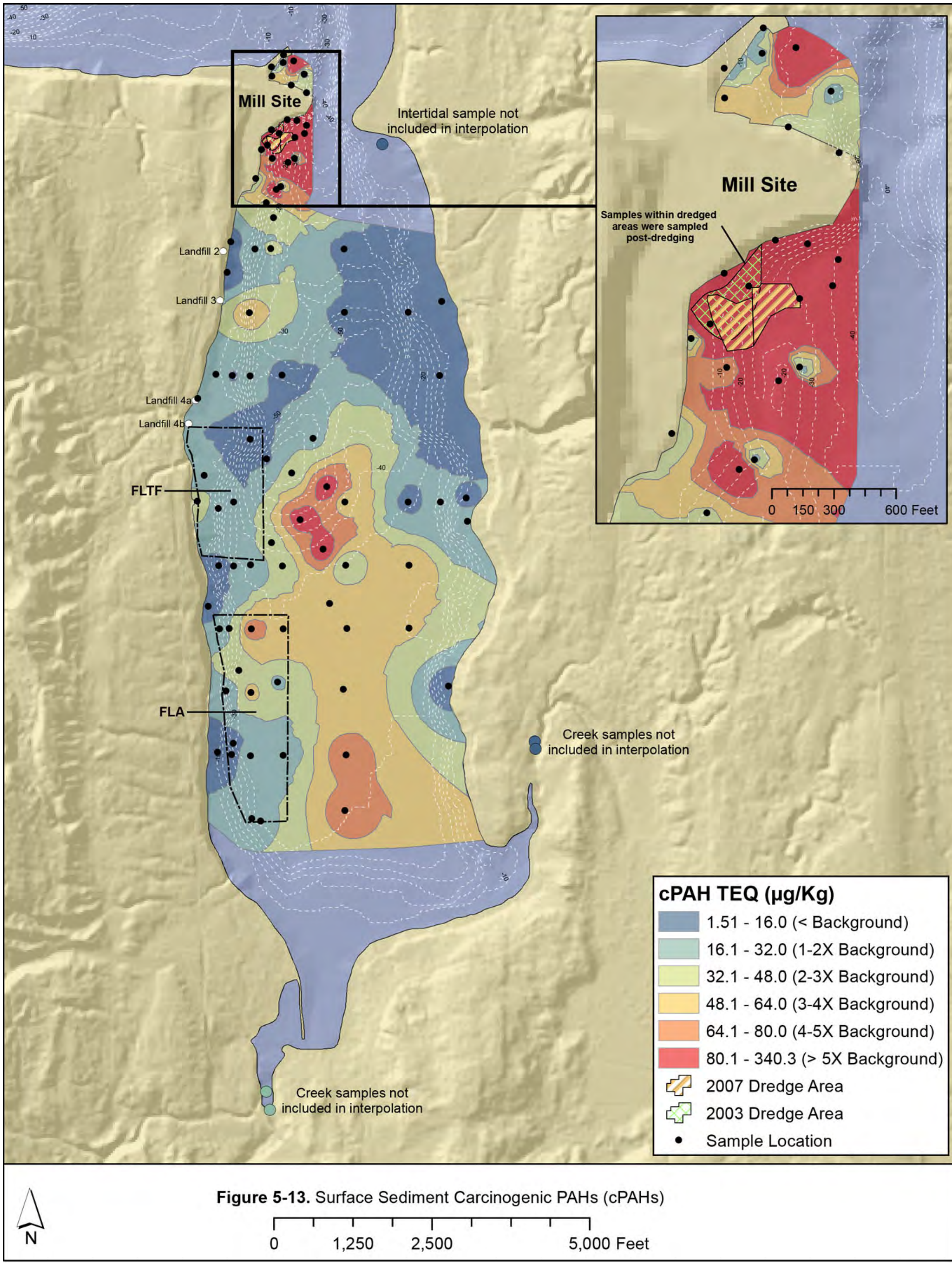


Figure 5-13. Surface Sediment Carcinogenic PAHs (cPAHs)

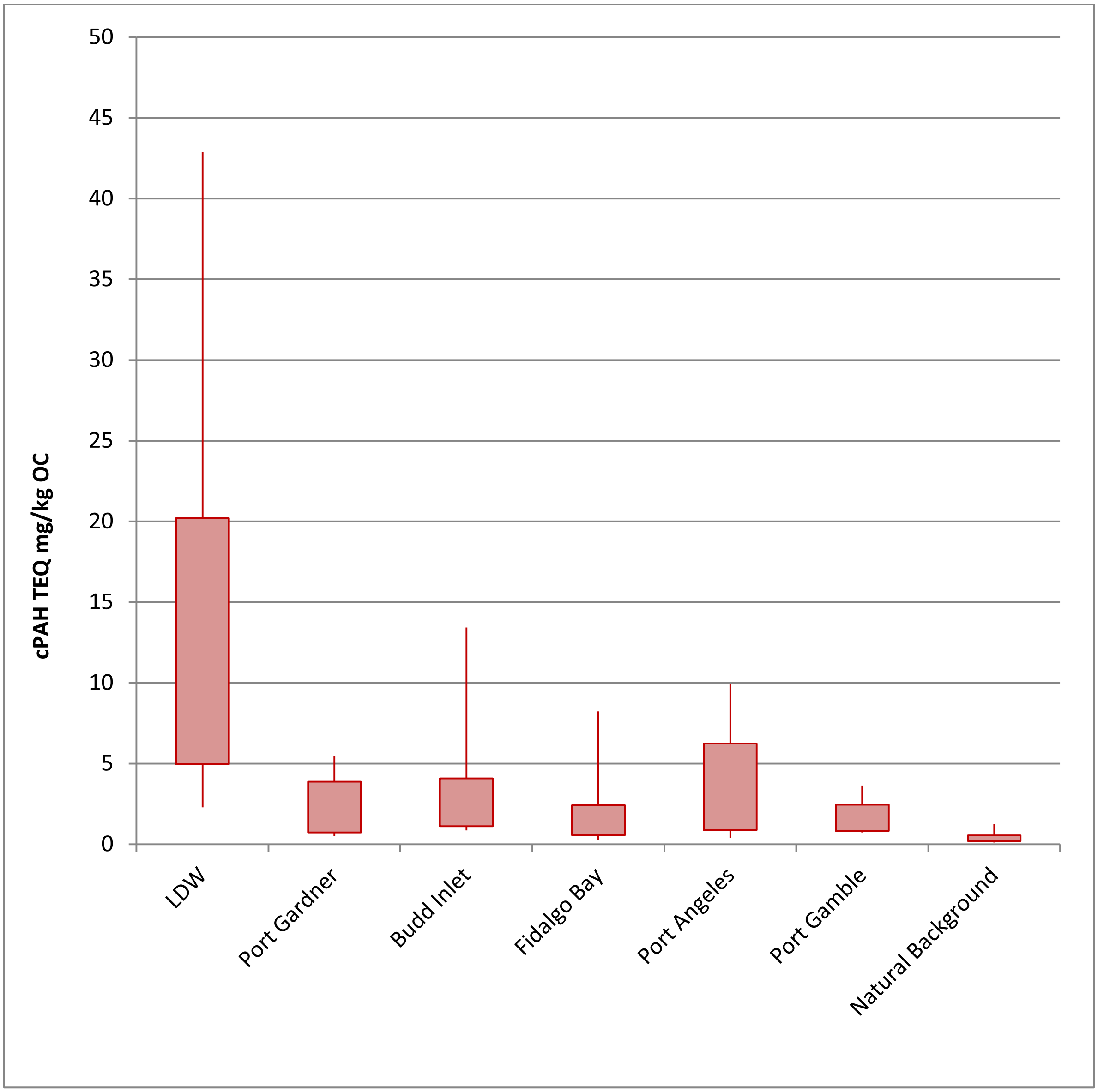


Figure 5-14. Surface Sediment cPAH Concentrations from Investigations Conducted in Puget Sound

Correlations between percent fines and the cPAH TEQ were investigated in the same manner as for metals. There were two unusually high TEQs, found at intertidal station MS-20 and subtidal station MS-11. A scatterplot excluding these outliers (Figure 5-15) indicates a fairly strong correlation for the stations in the bay, less so when stations near the mill are included.

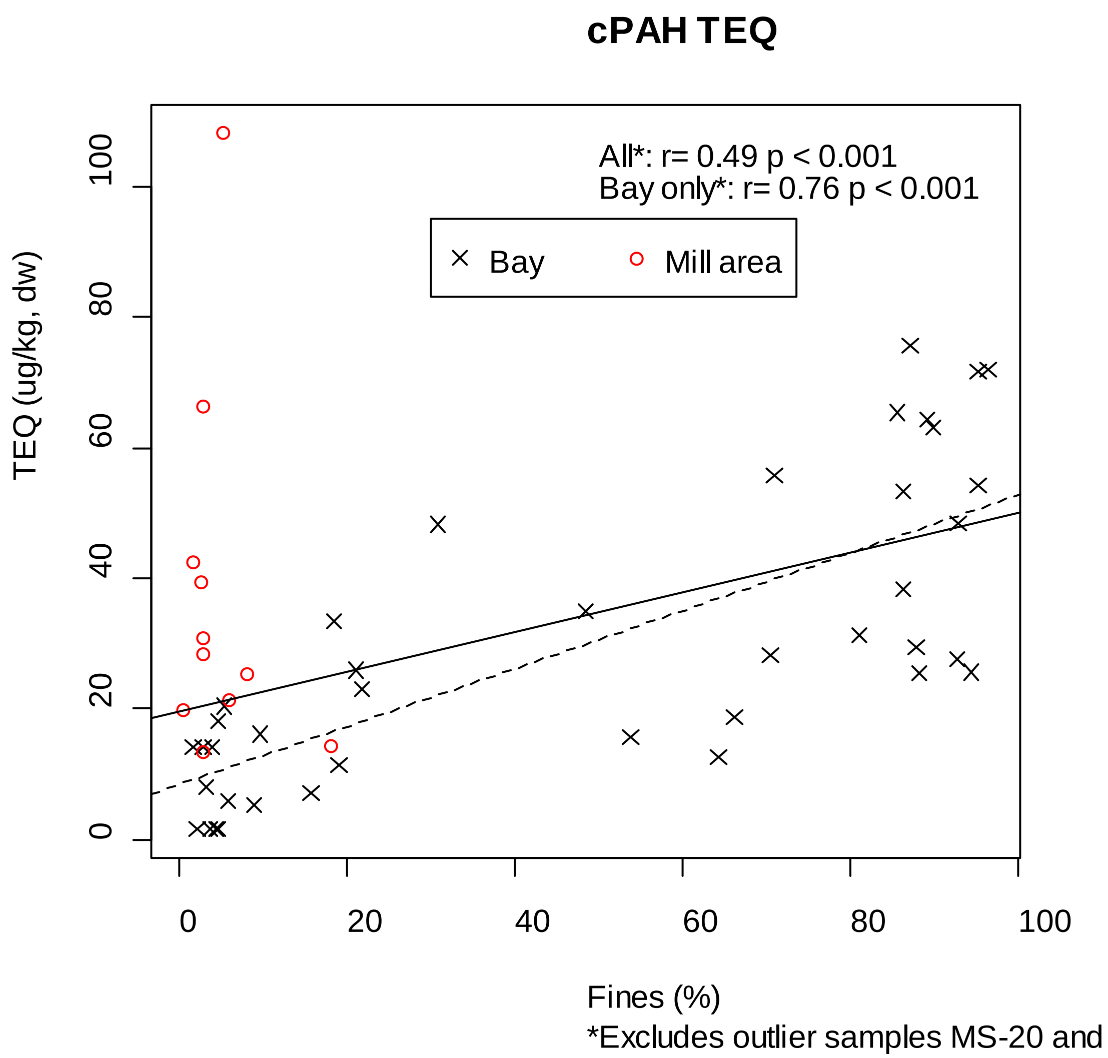


Figure 5-15. Correlations between Carcinogenic PAH TEQ Values and the Fine-Grained Sediment Fraction.

The best-fit regression line, the Pearson correlation coefficient (r), and its significance level (p) are shown. The solid line shows the best-fit regression line for all the data; the dashed line shows the best-fit regression line for the bay-only samples.

The ratios of different PAH compounds can sometimes be used to help identify potential sources. PAHs in sediments can be separated into two primary categories, petrogenic and pyrogenic. Petrogenic PAHs are directly derived from fossil fuels, particularly petroleum and its distillates. Sources of petrogenic PAHs include crude oil, fuel oils, lubricating oils, refined fuels such as diesel, and coal. Pyrogenic PAHs are formed during incomplete or inefficient combustion of fossil fuels and other organic matter at high temperatures. Sources of pyrogenic PAHs include wood burning emissions, automobile exhaust, and highway dust. Creosote and coal tar are also considered pyrogenic PAHs since they are created using controlled pyrolytic processes (Zemo 2009). There are also natural sources of petrogenic and pyrogenic PAHs.

PAHs are composed of multiple aromatic rings. In general, increasing the number of rings on a PAH compound increases the environmental stability of that compound. PAHs may also contain carbon side chains referred to as alkyl groups. PAHs that do not contain alkyl groups are referred to as nonalkylated, or parent PAHs (Stout 2003). Several statistical methods have been used to differentiate petrogenic and pyrogenic PAHs and to further identify individual sources. Most of these methods rely on a detailed evaluation of a suite of 40 or more PAHs, many of which are alkylated (Stout et al. 2002). However, the PAHs analyzed in Port Gamble sediments comprise the 16 "priority pollutant" parent PAH compounds. Statistical methods and their ability to distinguish between sources are more limited with this subset of data, particularly when there are multiple sources of PAHs and the overall concentrations of PAHs are relatively low. However, Zemo (2009), Stout (2003), and Stout and Graan (2010) have developed several tools that can be used to provide an indication of PAH sources using the 16 priority pollutant PAHs. These approaches were used in combination to evaluate the potential sources of PAHs in Port Gamble Bay.

Zemo (2009) developed a combination of ratios (double-ratio cross plots) to evaluate PAH sources in Puget Sound, particularly in the Duwamish Waterway and Elliott Bay. Isometric ratios are calculated between PAHs with the same molecular weight and number of rings to minimize the effects of environmental weathering on dissimilar structures (i.e., anthracene and phenanthrene degrade at similar rates by similar processes). To evaluate whether PAHs in Port Gamble Bay were more petrogenic or pyrogenic in nature, two ratio pairings were evaluated (Figure 5-16):

- Anthracene/(anthracene + phenanthrene) vs. fluoranthene/(fluoranthene + pyrene)
- Benzo(a)anthracene/ (benzo(a)anthracene + chrysene) vs. fluoranthene/(fluoranthene + pyrene)

Based on these pairings, the sediments in Port Gamble Bay appear to be pyrogenic in nature (derived from combustion) and do not appear to include more petrogenic sources (derived from petroleum).

Zemo (2009) also established a second set of cross plots with isometric relationships to better distinguish between PAHs associated with "urban background" sources and creosote-related PAHs. Urban background includes a variety of sources that may be present in the Port

Gamble Bay area, including wood burning emissions, automobile exhaust, and highway dust. For this site, the term "urban background" may be misleading, since the large volumes of wood waste burned over 150 years at the mill contribute to this signature and the surrounding area is not urban. Thus, this category of sources will be referred to as "airborne emissions" to distinguish it from creosote-related sources.

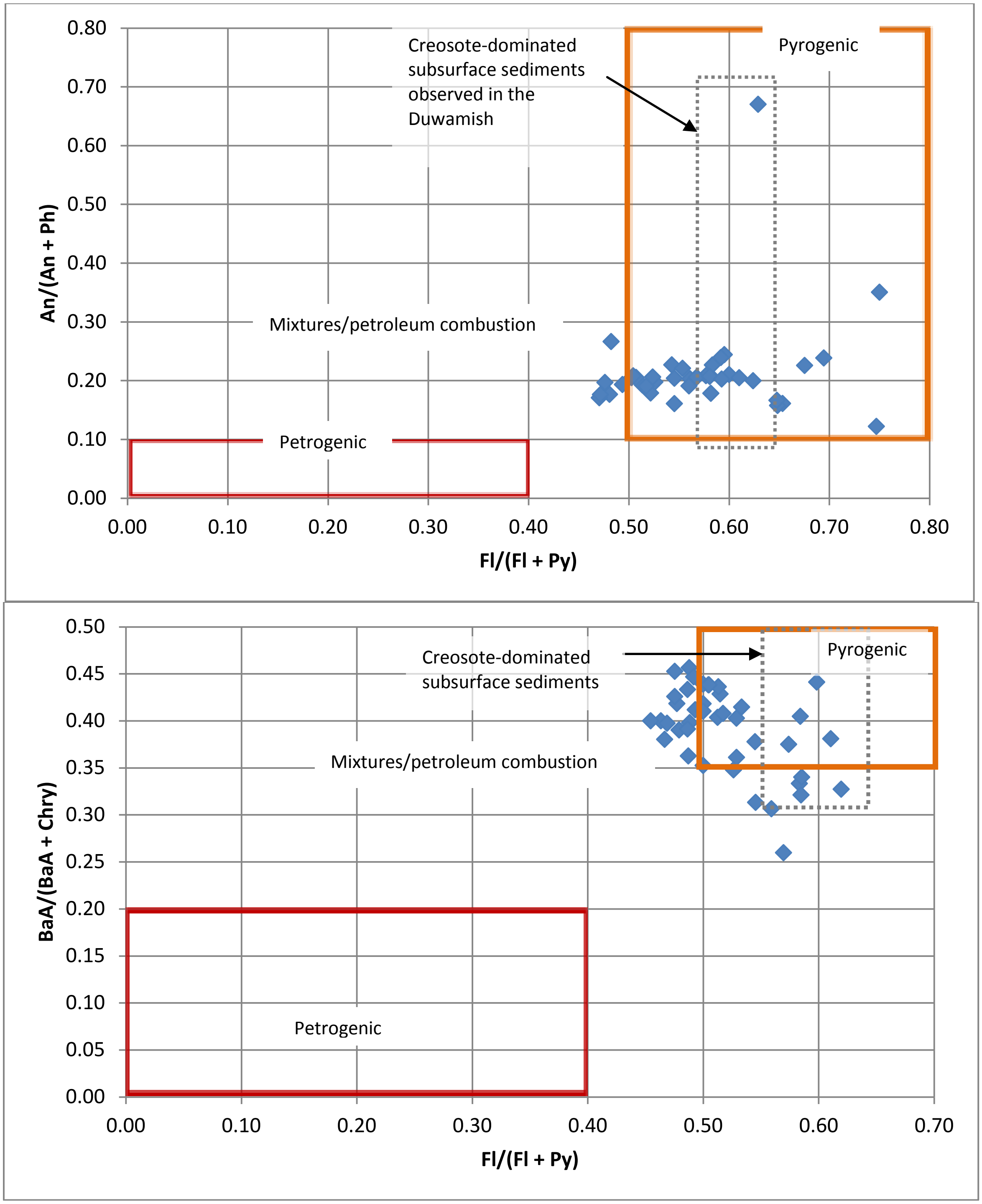


Figure 5-16. Cross-Plots of Selected PAHs Observed in Port Gamble Bay.
Values compared to ranges for petrogenic and pyrogenic PAHs established for Puget Sound (Zemo 2009).

The ratios used in this analysis were as follows:

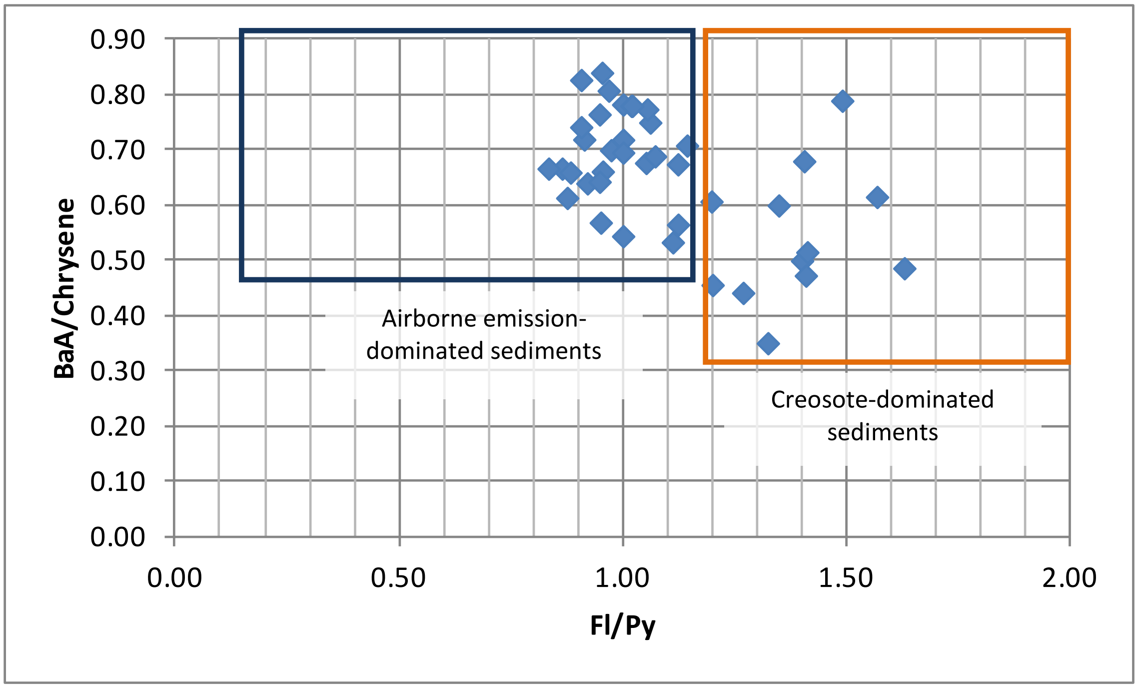
- Benzo(a)anthracene/chrysene vs. fluoranthene/pyrene
- Benzo(a)anthracene/ benzo(a)pyrene vs. fluoranthene/pyrene

Based on this analysis, the majority of samples collected in Port Gamble Bay fall into the ranges observed for airborne emissions (Figure 5-17). However, a subgroup of stations north and south of the former mill site had ratios similar to those of creosote-dominated sediments: Stations MS-11, 13, 14, 15, DV-02/03, and SG-1016, 1017, 1019, 1020, and 1021.

To further evaluate the sources of PAHs, a principal components analysis (PCA) was used to better understand the distribution of PAHs throughout the bay. The PCA helps determine which PAHs or groups of PAHs are most important in explaining the overall distribution of PAHs in the bay and provides a basis for grouping stations with similar distributions of PAHs. PCA is a statistical procedure that serves to reduce the number of variables that explain the variance in the PAH data set by creating new variables that are linear combinations of the original list of PAHs that show similar patterns among the samples. Components with eigenvalues greater than one were retained in the analysis and an orthogonal rotation was applied. The orthogonal rotation results in uncorrelated components. Two PCA analyses were run using normalized values for each PAH, with one-half the detection limit used for analytes with "U" values. Samples with a high number of non-detects were not included in the analysis. The first (Run A) included total benzofluoranthenes but excluded five samples for which no data were available for these analytes. The second (Run B) included the five samples but excluded benzofluoranthenes.

While the primary factors in the two runs differed slightly, the station groupings were very similar. For the purposes of this discussion, the second run with all stations not including total benzofluoranthenes will be used. Run B produced three factors with eigenvalues greater than one, which accounted for a cumulative 94% of the variance (69%, 17%, and 8%, respectively). Factor 1 was driven primarily by the HPAHs chrysene, benzo(a)pyrene, benzo(a)anthracene, and indeno(1,2,3-cd)pyrene. Factor 2 included the LPAHs naphthalene, anthracene, and phenanthrene. A third factor (fluorene, 2-methylnaphthalene, and acenaphthene) distinguished only one sample (DV-02) from the rest and was not plotted.

The majority of samples (Group A) in Port Gamble Bay were characterized by nearly equal distributions of Factors 1 and 2 (Figure 5-18). This is reflected in the relative proportions of LPAH and HPAH in the majority of the Port Gamble Bay sediments, which generally range from 40–50% for LPAHs and 50–60% for HPAHs. The relative proportions of PAHs for stations representative of this group (Station BW-11 and BW-19) are shown in Figure 5-19A.



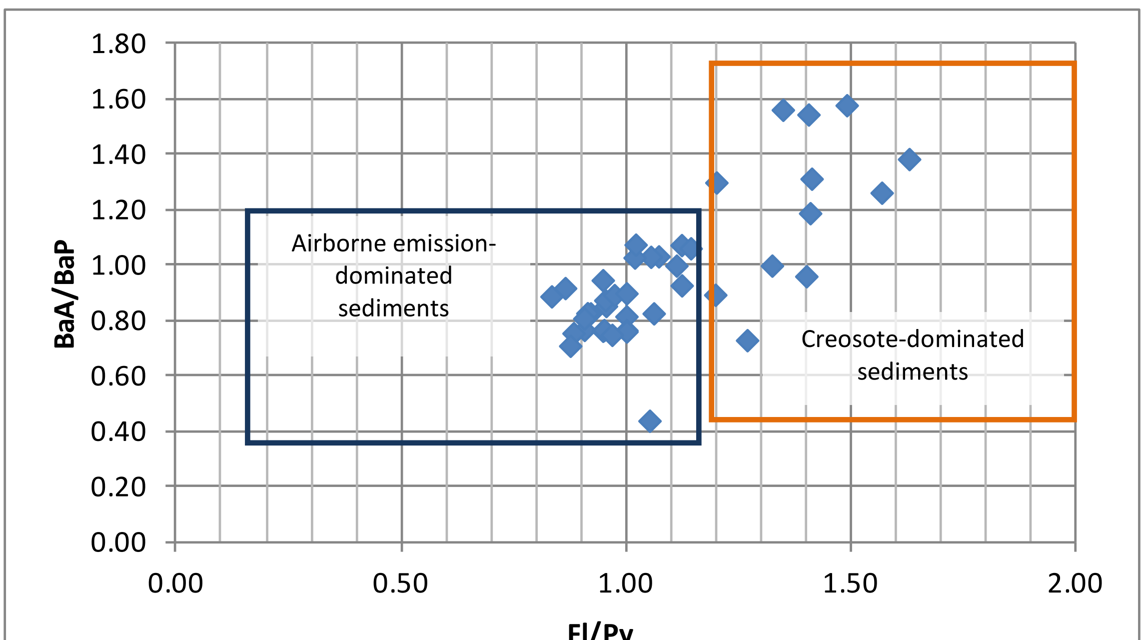


Figure 5-17. Cross-Plots of Selected PAHs Observed in Port Gamble Bay.

Values compared to ranges for urban sources (airborne emissions) and creosote-dominated

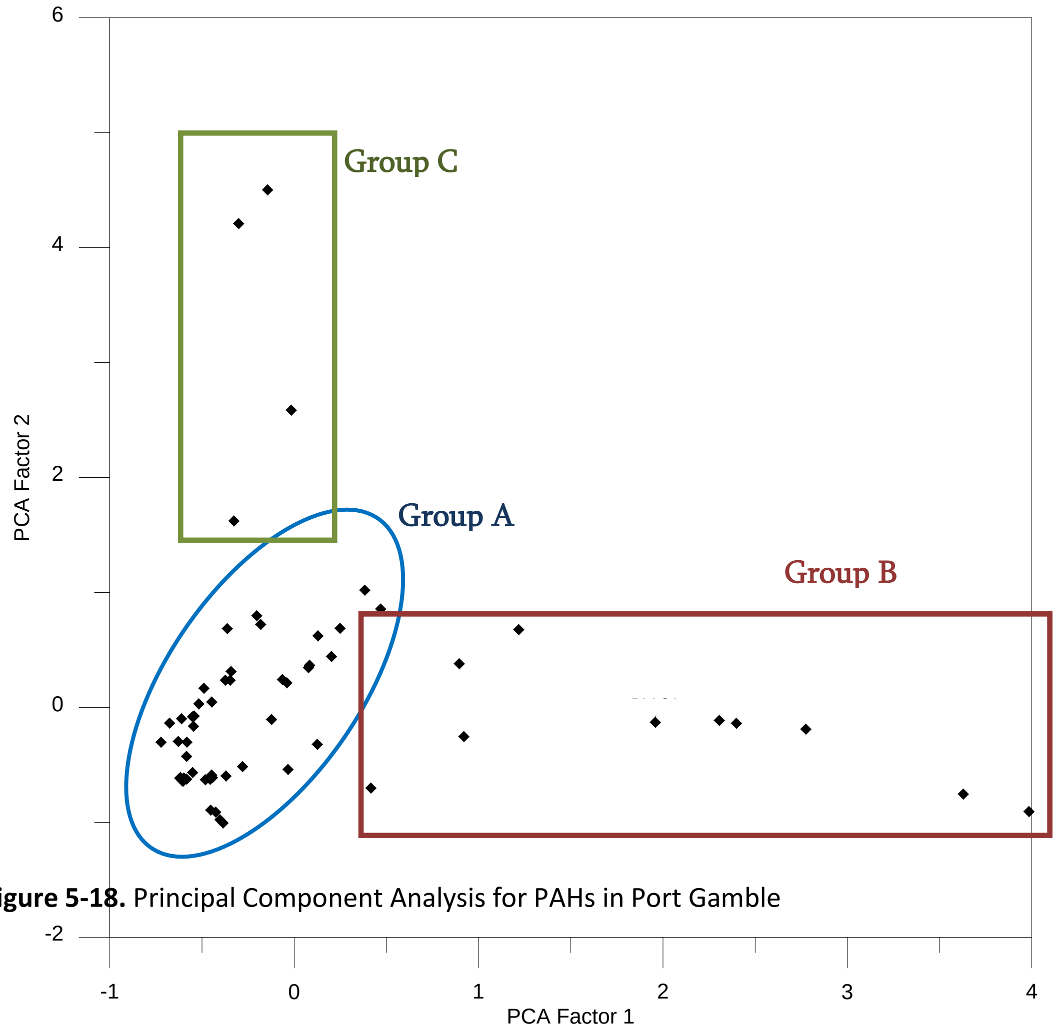


Figure 5-18. Principal Component Analysis for PAHs in Port Gamble

Group A

Group B

Group C

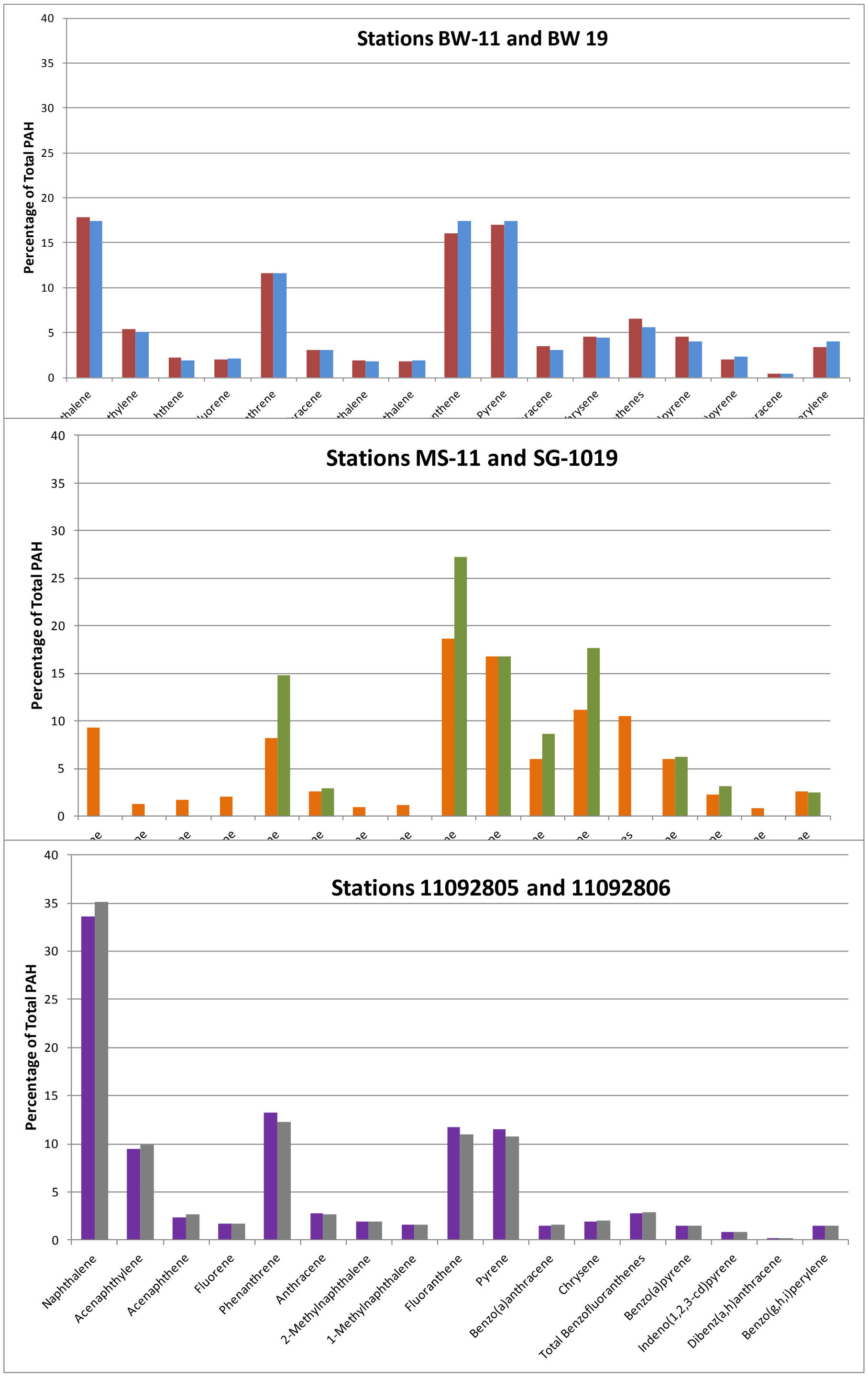


Figure 5- **19.**
Distributions of PAHs in Samples Representative of Groups A, B, and C

A second group of samples (Group B) were characterized by a higher proportion of HPAHs. This group included one station in the northern embayment (Stations MS-11), one station immediately south of the point (Station MS-13) and a group of stations along the boundary of the 2007 dredge area (Stations DV-01, 02/03, SG-1017, 1019, and 1020). As predicted by the PCA, these sediments have higher concentrations of HPAHs and the LPAHs comprise a small fraction of the total PAH (Figure 5-19B). These samples are suggestive of creosote-dominated sources.

The third group (Group C) is characterized by high proportions of LPAHs, in particular naphthalene, anthracene, and phenanthrene (Figure 5-19C). Group C included four stations located offshore of the log-transfer facility (PGST-03, 04, 05, and 06). It is unusual to see high concentrations of these easily weathered, short-chain PAHs in subtidal sediments. It is unclear why these stations are different; all four samples were collected during the same survey (PGST 2011), suggesting the potential for field contamination. It is interesting to note that two other stations collected during the same survey (PGST-01 and -02), as well as stations collected during the NewFields 2011 survey (Stations BW-04, BW-10, and BW-15), fell into Group A.

It is important to note that it is difficult to "fingerprint" the nature and sources of PAHs using the 16 priority pollutant PAHs alone. This is particularly true when there are low concentrations and a mixture of sources, as occurs in Port Gamble Bay. However, Zemo (2009), Stout (2003), and Stout and Graan (2010) provide some basis for comparison using priority PAHs, particularly in Puget Sound, since some of the defined relationships were developed in Puget Sound. Furthermore, the PAHs used in these relationships were detected in a majority of samples.

While there are limitations in this data set, it does appear that the PAHs detected in Port Gamble Bay are generally similar with several exceptions. The detected PAHs for most samples indicate a mixture of pyrogenic sources including both airborne emissions and creosote. A more detailed chemical analysis with alkylated PAHs and higher concentrations would be required to further distinguish among sources. For a subset of samples in the vicinity of the former mill, there does appear to be a group of samples of creosote origin. An additional group of stations were dominated by three LPAHs. It is unclear what the source is for these samples; however, these are easily degraded PAHs that are not typically found in subtidal sediments.

5.5.2 Phenols

Phenol was the most commonly detected ionizable SVOC, found in 25 of 51 subtidal samples in the bay, 12 of 15 samples near the mill, and 10 of 14 intertidal samples (Figure 5-20, Tables 5-7, 5-8). Two samples within the FLA, PGSS-8 AND PGSS-22, exceeded the SQS screening level of 420 mg/kg and one sample collected just east of the FLTF, PGSS-58, also exceeded the SQS criterion. One sample in the north embayment near the mill had the highest concentration of 3900 mg/kg. Most other phenol detections were in samples collected from the western edge of the bay between the FLTF and the former mill. Levels in intertidal sediments were lower, ranging up to 92 µg/kg, below the SQS. Phenol is generally correlated with the presence of wood, high TVS/TOC ratio, sulfide, and ammonia. Phenol is a product of wood degradation and is also a component of creosote.

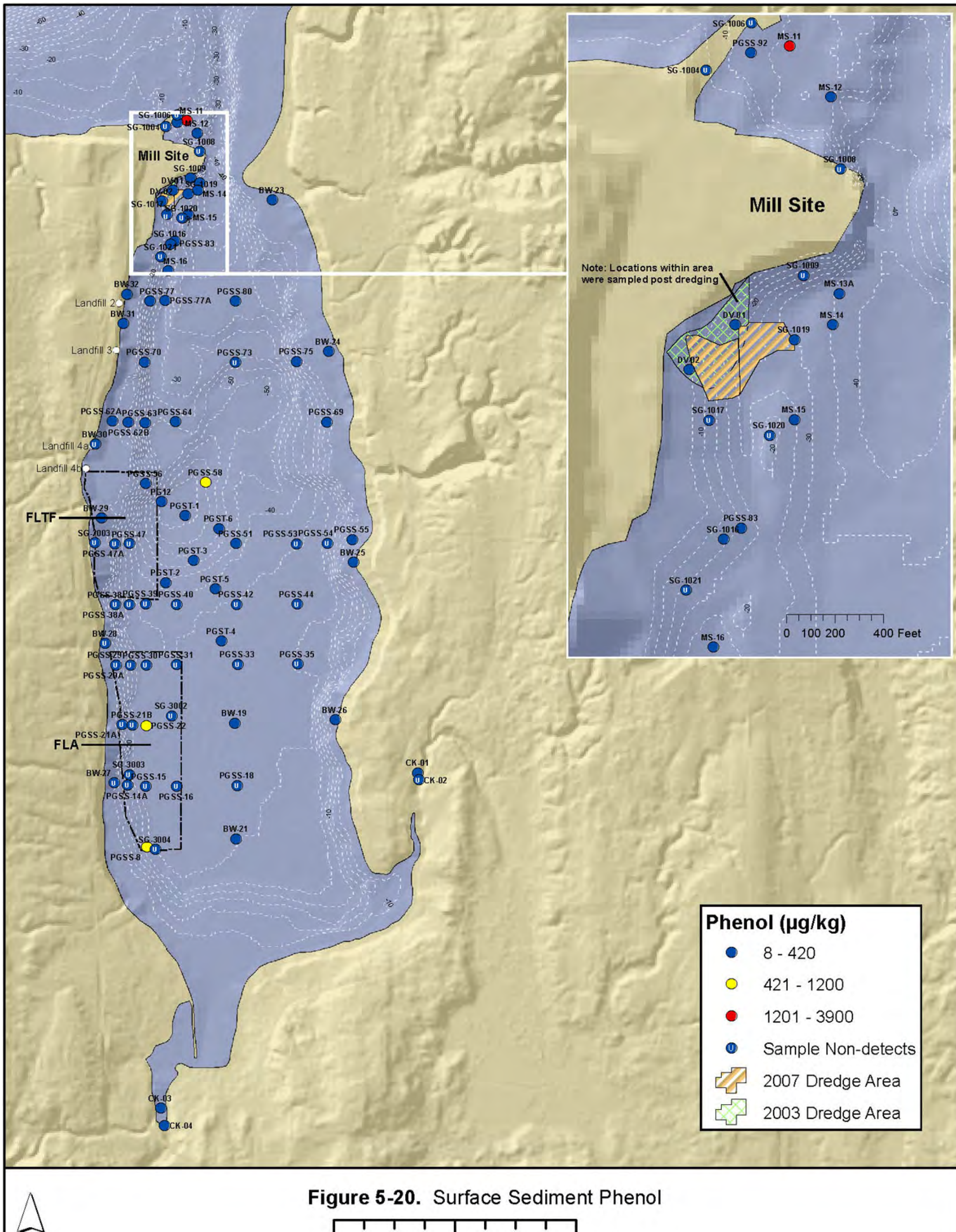


Figure 5-20. Surface Sediment Phenol

Table 5-7. Summary of Sediment Semivolatile Organic Compound (SVOC) Results – Dry Weight

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
Chlorinated Benzenes in µg/kg												
1,2-Dichlorobenzene	51	0	2.4	40	19.1	20	15	0	2.3	20	5.71	14.1
1,3-Dichlorobenzene	51	0	2.5	40	19.1	20	13	0	2.4	20	5.99	16.6
1,4-Dichlorobenzene	51	0	2.8	40	19.1	20	15	1	2.6	20	6.11	14.1
1,2,4-Trichlorobenzene	51	0	2.1	40	19	20	15	1	2.1	20	7.31	16.2
Hexachlorobenzene	51	0	2.1	40	19	20	15	1	2.1	20	9.61	19.6
Phthalate Esters in µg/kg												
Dimethylphthalate	51	0	2.8	47	21	20	15	1	2.7	39	14.4	32.8
Diethylphthalate	51	1	19	50	26.3	48	15	1	11	39	28.5	35.6
Di-n-Butylphthalate	51	0	7.9	47	21.2	20	15	2	7.5	39	17	32.8
Butylbenzylphthalate	51	0	5.9	47	21.1	20	15	1	4.6	39	15.5	32.8
bis(2-Ethylhexyl)phthalate	51	5	11	50	23.4	39	15	7	9.8	92	28.8	57.4
Di-n-Octyl phthalate	51	0	5.6	47	21.1	20	15	2	3.7	54	17.2	37.8
Miscellaneous Compounds in µg/kg												
Dibenzofuran	51	9	5.2	110	26.7	45	15	8	6.6	118.5	32.8	50.4
Hexachlorobutadiene	51	0	2.1	99	19.5	20	15	1	2.1	23	10.2	21.2
N-Nitrosodiphenylamine	51	0	5.2	40	20	20	15	1	4.9	20	10.6	19.6
Guaiacol	39	0	19	40	20.9	20	2	0	19	20	19.5	19.9
Retene	39	4	10	110	23.2	20	2	0	19	20	19.5	19.9
Ionizable Organic Compounds in µg/kg												
Phenol	51	25	19	720	90.5	220	15	12	12	3900	333	230
2-Methylphenol	51	0	5.1	40	20	20	15	2	4.8	20	11.5	19.6
4-Methylphenol	51	13	18	240	47.7	120	15	9	15	1850	165	112
2,4-Dimethylphenol	51	0	3.3	40	20.3	20	15	2	3.2	86	16.9	20
Pentachlorophenol	51	0	47	200	117	190	15	1	27	160	75.3	134
Benzyl Alcohol	51	0	5.9	47	21.1	20	15	2	5.6	39	17.2	32.8
Benzoic Acid	51	8	97	600	205	230	15	2	93	785	203	322
Intertidal Samples												
Chlorinated Benzenes in µg/kg												
1,2-Dichlorobenzene	15	0	2.2	2.7	2.38	2.4	4	0	2.1	3	2.67	2.94
1,3-Dichlorobenzene	15	0	2.3	2.7	2.49	2.6	4	0	2.1	3	2.67	2.94
1,4-Dichlorobenzene	15	0	2.5	2.8	2.7	2.8	4	0	2.1	3	2.67	2.94
1,2,4-Trichlorobenzene	15	0	2.1	3.4	3.22	3.4	4	0	1.7	1.8	1.75	1.8
Hexachlorobenzene	15	0	2.1	4.2	3.91	4.2	4	0	1.7	1.8	1.75	1.8
Phthalate Esters in µg/kg												
Dimethylphthalate	15	0	2.6	21	3.95	2.8	4	0	16.0	18	17.5	18
Diethylphthalate	15	1	13	36	32.2	35.6	4	0	16.0	18	17.5	18
Di-n-Butylphthalate	15	0	7.3	21	8.59	7.96	4	0	16.0	18	17.5	18

Table 5-7. Summary of Sediment Semivolatile Organic Compound (SVOC) Results – Dry Weight

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Butylbenzylphthalate	15	1	5.5	29	7.35	6	4	0	16.0	18	17.5	18
bis(2-Ethylhexyl)phthalate	15	1	13	21	14.2	14	4	1	16.0	22	18.5	20.8
Di-n-Octyl phthalate	15	0	5.2	21	6.55	5.7	4	0	16.0	18	17.5	18
Miscellaneous Compounds in µg/kg												
Dibenzofuran	15	6	1.7	26	6.94	19.8	10	5	1.8	18	12.9	18
Hexachlorobutadiene	15	0	2.1	4.5	4.17	4.4	4	0	1.7	1.8	1.75	1.8
N-Nitrosodiphenylamine	15	0	4.8	10	5.41	5.26	4	0	8.0	9	8.75	9
Ionizable Organic Compounds in µg/kg												
Phenol	15	10	7.7	92	26.3	43.2	4	0	16.0	18	17.5	18
2-Methylphenol	15	1	4.7	11	5.69	8.04	4	0	8.0	9	8.75	9
4-Methylphenol	15	0	5.9	21	7.23	6.46	4	0	16.0	18	17.5	18
2,4-Dimethylphenol	15	0	3.1	10	3.72	3.4	4	0	8.0	9	8.75	9
Pentachlorophenol	15	0	43	82	48.2	47.6	4	0	66.0	74	70.3	73.1
Benzyl Alcohol	15	0	5.4	3300	226	15	4	0	16.0	18	17.5	18
Benzoic Acid	15	2	90	750	165	328	4	0	82.0	92	87.8	91.1

Non-detects included in descriptive statistics.

Table 5-8. Summary of Sediment Semivolatile Organic Compound (SVOC) Results – Organic Carbon Normalized

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
Chlorinated Benzenes in mg/kg OC												
1,2-Dichlorobenzene	51	0	0.11	6.1	1	1.5	15	0	0.015	1	0.234	0.624
1,3-Dichlorobenzene	51	0	0.12	6.1	1	1.5	13	0	0.062	1	0.27	0.646
1,4-Dichlorobenzene	51	0	0.13	6.1	1	1.5	15	1	0.022	1	0.246	0.652
1,2,4-Trichlorobenzene	51	0	0.12	6.1	1	1.5	15	1	0.017	1	0.277	0.732
Hexachlorobenzene	51	0	0.12	6.1	1	1.5	15	1	0.024	1	0.333	0.846
Phthalate Esters in mg/kg OC												
Dimethylphthalate	51	0	0.13	6.1	1.07	1.6	15	1	0.021	1.9	0.465	0.864
Diethylphthalate	51	1	0.4	6.1	1.24	1.9	15	1	0.067	8.3	1.56	2.1
Di-n-Butylphthalate	51	0	0.37	6.1	1.08	1.6	15	2	0.034	1.9	0.633	1.48
Butylbenzylphthalate	51	0	0.27	6.1	1.08	1.6	15	1	0.017	1.9	0.567	1.24
bis(2-Ethylhexyl)phthalate	51	5	0.36	6.1	1.14	1.6	15	7	0.12	3.3	0.974	2.14
Di-n-Octyl phthalate	51	0	0.26	6.1	1.08	1.6	15	2	0.014	1.9	0.607	1.36
Miscellaneous Compounds in mg/kg OC												
Dibenzofuran	51	9	0.16	610	14.6	2.7	15	8	0.15	3.3	1.03	1.78
Hexachlorobutadiene	51	6	0.12	6.1	1.02	2	15	1	0.016	1	0.349	0.864
N-Nitrosodiphenylamine	51	0	0.24	6.1	1.04	1.5	15	1	0.025	1.2	0.414	0.964
Intertidal Samples												
Chlorinated Benzenes in mg/kg OC												
1,2-Dichlorobenzene	15	0	0.029	0.94	0.37	0.618	4	0	0.18	3.5	1.22	2.75
1,3-Dichlorobenzene	15	0	0.031	0.98	0.38	0.644	4	0	0.18	3.5	1.22	2.75
1,4-Dichlorobenzene	15	0	0.034	1.1	0.42	0.694	4	0	0.18	3.5	1.22	2.75
1,2,4-Trichlorobenzene	15	0	0.042	1.3	0.5	0.856	4	0	0.12	2.1	0.74	1.64
Hexachlorobenzene	15	0	0.05	1.6	0.62	1.06	4	0	0.12	2.1	0.74	1.64
Phthalate Esters in mg/kg OC												
Dimethylphthalate	15	0	0.034	1.8	0.53	0.952	4	0	1.2	20	7.18	15.8
Diethylphthalate	15	1	0.24	14	5.25	8.88	4	0	1.2	20	7.18	15.8
Di-n-Butylphthalate	15	0	0.096	3.1	1.28	2.02	4	0	1.2	20	7.18	15.8
Butylbenzylphthalate	15	1	0.072	2.4	1.03	2.02	4	0	1.2	20	7.18	15.8
bis(2-Ethylhexyl)phthalate	15	1	0.17	5.5	2.17	3.56	4	1	1.5	20	7.25	15.8
Di-n-Octyl phthalate	15	0	0.068	2.2	0.94	1.68	4	0	1.2	20	7.18	15.8
Miscellaneous Compounds in mg/kg OC												
Dibenzofuran	15	6	0.033	1.8	0.61	1.2	10	5	0.19	20	3.75	7.4
Hexachlorobutadiene	15	0	0.054	1.7	0.66	1.12	4	0	0.12	2.1	0.74	1.64
N-Nitrosodiphenylamine	15	0	0.063	2	0.81	1.32	4	0	0.6	10	3.59	7.9

Non-detects included in descriptive statistics.

In addition to phenol, 4-methylphenol was detected in 22 of 66 subtidal samples and 2-methylphenol was detected in 2 of 66 subtidal and 1 of 14 intertidal samples. Two of these samples near the mill site exceeded the CSL for 4-methylphenol. These compounds are also often associated with wood waste as well as creosote. None of the phenols or other ionizable organic compounds detected are considered contaminants of concern for human health (see Section 8).

5.5.3 Other Semivolatile Analytes

Diethylphthalate, bis(2-ethylhexyl)phthalate, dibenzofuran, retene, and benzoic acid were detected at 1–5 subtidal stations each at levels below the SQS. Diethylphthalate, dibenzofuran, and benzoic acid were also detected at 1-6 intertidal stations each, at levels below the SQS. Phthalates are often associated with stormwater outfalls. Dibenzofuran is a constituent of creosote, while retene and benzoic acid are degradation products of wood waste. None of these compounds is considered a contaminant of concern for human health (see Section 8).

5.6 Polychlorinated Biphenyls

Aroclor 1254 was detected in two samples in the bay at concentrations below the SQS screening criterion (Tables 5-9, 5-10). Aroclors 1242 and 1260 were detected in two samples near the former mill, and one of these samples exceeded the SQS criterion.

To evaluate human health risks from recreational and tribal use of beach areas, including general beach use and shellfish collection activities, PCB congeners were analyzed at all 14 intertidal sediments (Table 5-11, Figure 5-21). At least some PCB congeners were detected at all stations, and dioxin-like PCB congener TEQs (corresponding to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) equivalents) ranged from 0.0059–0.197 ng/kg in the bay and 0.014–0.0572 near the former mill. The highest concentration was located at station BW-27 near the FLA.

5.7 Dioxins/Furans

Analytical results for dioxins/furans expressed as 2,3,7,8-TCDD toxic equivalents (TEQs) are presented in Table 5-12 and Figure 5-22. TEQs were calculated using the World Health Organization (WHO) 2005 toxic equivalency factors (TEF) for mammals, because dioxins/furans are considered contaminants of concern for human health and are not of concern to benthic organisms. Values were calculated using the KM approach with 1/2 the detection limit for non-detected results (see Section 8).

Dioxin/furan congeners were detected in all samples. Total TEQ concentrations ranged from 0.34–6.5 ng/kg in the bay, with the highest concentrations located in the central fine-grained portion of the bay. Dioxin/furan congeners were also measured in all 14 intertidal samples around the bay, and TEQs ranged from 0.162–2.04 ng/kg, somewhat lower than in subtidal sediments. At intertidal stations near the mill, dioxin/furan TEQs ranged from 1.23–16 ng/kg, with the highest concentrations along the southern shoreline of the former mill.

Table 5-9. Summary of Sediment Polychlorinated Biphenyl (PCB) Aroclor Results – Dry Weight

	Bay-wide Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
PCBs in µg/kg												
Aroclor 1016	48	0	3.8	20	6.34	19	11	0	3.7	21	6.93	19
Aroclor 1221	48	0	3.8	20	6.5	19	11	0	3.7	19	5.57	6.1
Aroclor 1232	48	0	3.8	20	6.5	19	11	0	3.7	21	6.93	19
Aroclor 1242	48	0	3.8	20	6.34	19	11	1	3.7	115	16.9	21
Aroclor 1248	48	0	3.8	20	6.34	19	11	0	3.7	19	6.75	19
Aroclor 1254	48	2	3.8	20	6.55	19	11	0	3.7	19	6.02	11
Aroclor 1260	48	0	3.8	20	6.34	19	11	1	3.7	42.5	9.22	19
Aroclor 1262	41	0	3.8	6.1	4.08	4	8	0	3.7	3.9	3.84	3.9
Aroclor 1268	41	0	3.8	6.1	4.08	4	8	0	3.7	3.9	3.84	3.9
Total PCBs	48	2	3.8	20	6.8	19	11	1	3.7	157.5	20.7	21

Non-detects included in descriptive statistics.

Table 5-10. Summary of Sediment Polychlorinated Biphenyl (PCB) Aroclor Results – Organic Carbon Normalized

	Bay-wide Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
PCBs in mg/kg OC												
Aroclor 1016	48	0	0.077	1.2	0.273	0.509	11	0	0.041	0.92	0.238	0.23
Aroclor 1221	48	0	0.077	1.2	0.278	0.509	11	0	0.021	0.92	0.234	0.23
Aroclor 1232	48	0	0.077	1.2	0.277	0.509	11	0	0.041	0.92	0.238	0.23
Aroclor 1242	48	0	0.077	1.2	0.273	0.509	11	1	0.071	0.92	0.311	0.84
Aroclor 1248	48	0	0.077	1.2	0.273	0.509	11	0	0.041	0.92	0.238	0.23
Aroclor 1254	48	2	0.077	1.2	0.281	0.554	11	0	0.037	0.92	0.235	0.23
Aroclor 1260	48	0	0.077	1.2	0.273	0.509	11	1	0.031	0.92	0.259	0.31
Aroclor 1262	41	0	0.077	1.2	0.227	0.36	8	0	0.13	0.92	0.285	0.437
Aroclor 1268	41	0	0.077	1.2	0.227	0.36	8	0	0.13	0.92	0.285	0.437
Total PCBs	48	2	0.077	1.2	0.289	0.554	11	1	0.071	1.13	0.337	0.92

Non-detects included in descriptive statistics.

Table 5-11. Summary of Polychlorinated Biphenyl (PCB) Congener Results – Dry Weight

	Bay-wide Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Intertidal Samples												
PCB Congeners in pg/g												
PCB-077	14	14	0.423	5.26	2.18	4.58	6	6	1.14	13.3	6.99	11.3
PCB-081	14	1	0.0627	0.316	0.152	0.217	6	1	0.09	0.566	0.323	0.497
PCB-105	14	14	1.88	547.5	53.4	54.5	6	5	13.90	69.4	45.9	65.3
PCB-114	14	11	0.09	27.4	2.59	2.59	6	6	0.48	3.34	2.06	3.1
PCB-118	14	14	4.15	1267	122	120	6	6	28.70	148	97.5	141
PCB-123	14	10	0.1	19.735	2.07	2.11	6	5	0.57	3.31	2.16	3.12
PCB-126	14	3	0.0559	1.95	0.491	1.03	6	0	0.13	0.484	0.343	0.469
PCB-156/157	14	13	0.452	157.7	17.5	20.9	6	6	6.15	37.2	16.6	30.1
PCB-167	14	12	0.183	47.75	6.33	10.6	6	6	2.35	15.5	6.14	11.8
PCB-169	14	0	0.0704	1.13	0.242	0.329	6	0	0.09	0.612	0.218	0.401
PCB-170	14	13	1.04	259	35.4	72.2	6	6	10.90	234	57.4	135
PCB-180/193	14	14	2.25	1010	110	142	6	6	22.10	574	144	330
PCB-189	14	10	0.0555	8.37	1.34	2.68	6	5	0.38	8.79	2.19	5.1
PCB TEQ	14	14	0.00587	0.197	0.0547	0.116	6	6	0.014	0.0572	0.0408	0.0568

Non-detects included in descriptive statistics.

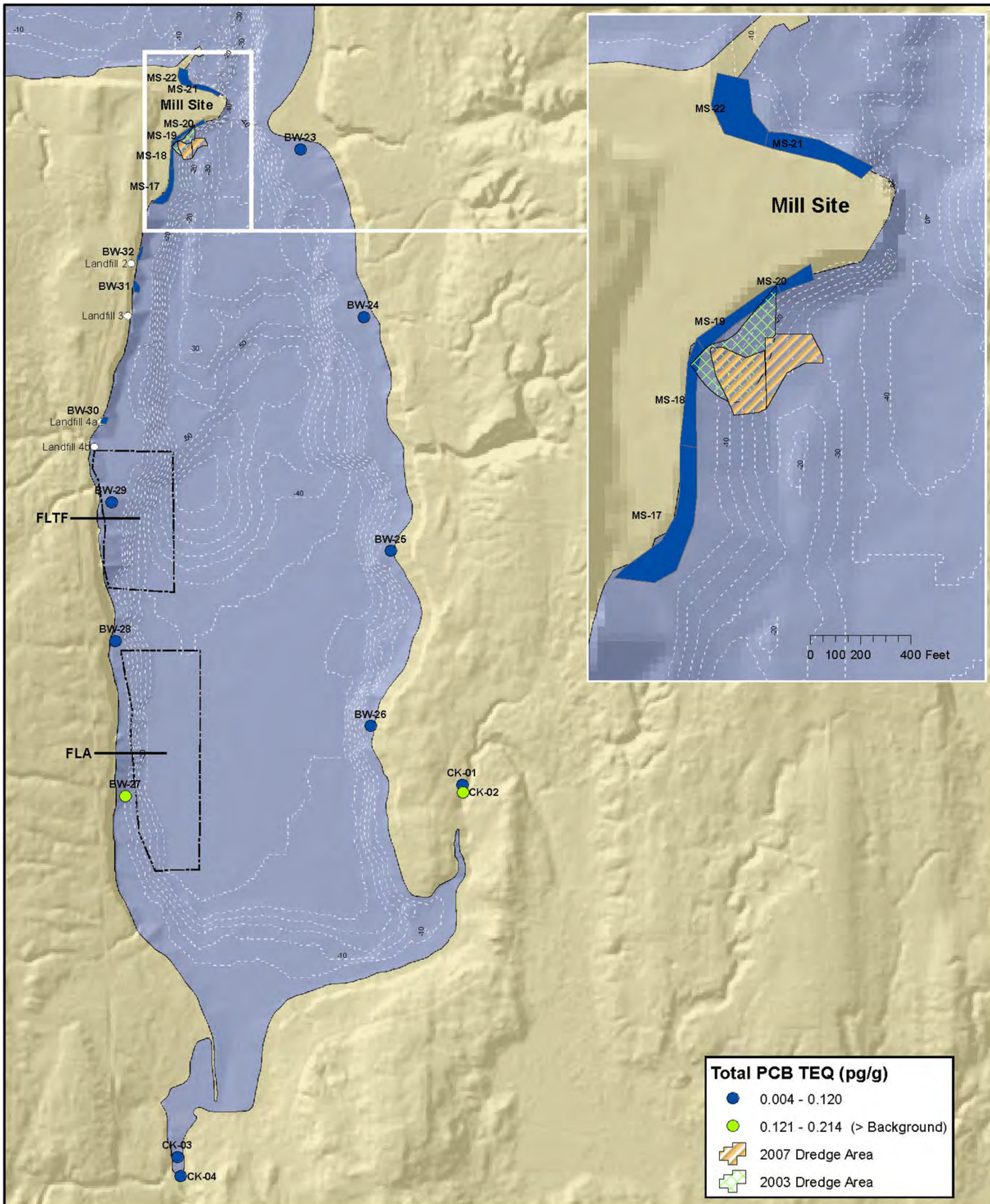


Figure 5-21. Surface Sediment PCB TEQ

Table 5-12. Summary of Sediment Dioxin/Furan Congener Results

	Bay-wide Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Results												
Dioxins/furans in ng/kg												
2,3,7,8-TCDD	18	5	0.0877	1.02	0.395	0.729	1	0	0.11	0.11	0.11	0.11
1,2,3,7,8-PeCDD	18	9	0.242	2.25	0.991	1.78	1	1	0.555	0.555	0.555	0.555
1,2,3,4,7,8-HxCDD	18	7	0.356	2.44	0.982	1.68	1	0	0.375	0.375	0.375	0.375
1,2,3,6,7,8-HxCDD	18	13	0.376	6.05	2.87	5.77	1	1	2.38	2.38	2.38	2.38
1,2,3,7,8,9-HxCDD	18	12	0.206	6.11	2.76	5.33	1	1	1.17	1.17	1.17	1.17
1,2,3,4,6,7,8-HpCDD	18	18	1.42	105	45.2	86.4	1	1	89.8	89.8	89.8	89.8
OCDD	18	18	10.5	1000	403	798	1	1	922	922	922	922
2,3,7,8-TCDF	18	15	0.099	4	2	3.63	1	1	0.832	0.832	0.832	0.832
1,2,3,7,8-PeCDF	18	12	0.279	1.69	0.851	1.53	1	1	0.413	0.413	0.413	0.413
2,3,4,7,8-PeCDF	18	12	0.228	2.27	1.01	1.8	1	0	0.241	0.241	0.241	0.241
1,2,3,4,7,8-HxCDF	18	9	0.502	1.84	0.994	1.64	1	0	0.529	0.529	0.529	0.529
1,2,3,6,7,8-HxCDF	18	7	0.12	1.17	0.537	1.06	1	0	0.127	0.127	0.127	0.127
1,2,3,7,8,9-HxCDF	18	2	0.0508	0.344	0.18	0.275	1	0	0.244	0.244	0.244	0.244
2,3,4,6,7,8-HxCDF	18	10	0.274	1.36	0.684	1.21	1	1	0.537	0.537	0.537	0.537
1,2,3,4,6,7,8-HpCDF	18	17	0.504	15.7	7.3	14	1	1	8.08	8.08	8.08	8.08
1,2,3,4,7,8,9-HpCDF	18	7	0.295	0.804	0.596	0.773	1	0	0.547	0.547	0.547	0.547
OCDF	18	17	0.649	36.9	15.6	31.5	1	1	26	26	26	26
Dioxin/furan TEQ	18	*	0.344	6.50	3.13	6.01	1	*	2.40	2.40	2.40	2.40
Intertidal Results												
Dioxins/furans in ng/kg												
2,3,7,8-TCDD	14	1	0.073	0.3	0.136	0.251	6	4	0.10	0.272	0.182	0.253
1,2,3,7,8-PeCDD	14	11	0.055	0.638	0.226	0.507	6	5	0.34	0.821	0.582	0.778
1,2,3,4,7,8-HxCDD	14	12	0.052	0.656	0.243	0.599	6	6	0.42	4.1	1.48	2.69
1,2,3,6,7,8-HxCDD	14	13	0.151	1.72	0.647	1.38	6	6	1.90	12.5	5.06	8.65
1,2,3,7,8,9-HxCDD	14	8	0.147	1.88	0.687	1.44	6	4	1.13	24.1	6.37	14.8
1,2,3,4,6,7,8-HpCDD	14	14	1.36	45.9	9.29	17.6	6	6	9.18	956	206	576
OCDD	14	14	10.8	356	66.2	106	6	6	40.00	9290	2050	5870
2,3,7,8-TCDF	14	13	0.207	1.3	0.459	0.824	6	4	0.25	0.592	0.369	0.509
1,2,3,7,8-PeCDF	14	9	0.0474	0.772	0.203	0.373	6	5	0.10	0.577	0.344	0.522
2,3,4,7,8-PeCDF	14	8	0.057	0.93	0.25	0.483	6	6	0.15	0.376	0.297	0.368
1,2,3,4,7,8-HxCDF	14	9	0.054	0.802	0.244	0.442	6	6	0.24	6.19	1.73	3.91
1,2,3,6,7,8-HxCDF	14	11	0.0474	0.617	0.174	0.356	6	6	0.23	1.48	0.573	1.01
1,2,3,7,8,9-HxCDF	14	2	0.0468	0.076	0.0569	0.0728	6	1	0.05	0.076	0.0565	0.0705
2,3,4,6,7,8-HxCDF	14	4	0.0474	0.59	0.166	0.333	6	5	0.20	0.754	0.434	0.657
1,2,3,4,6,7,8-HpCDF	14	13	0.298	4.45	1.39	2.67	6	6	2.93	41.3	18.6	41
1,2,3,4,7,8,9-HpCDF	14	7	0.0474	0.336	0.118	0.168	6	4	0.12	3.24	0.97	2.15
OCDF	14	8	0.44	5.27	2.14	4.51	6	6	2.52	214	51.1	133

Table 5-12. Summary of Sediment Dioxin/Furan Congener Results

	Bay-wide Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90^{th} %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Dioxin/furan TEQ	14	*	0.162	2.04	0.697	1.37	6	*	1.23	16.0	4.87	10.5

Non-detects included in descriptive statistics.

* TEQs shown in this table used the method described in Section 8.2.4. Using this method, all final estimated TEQ values are treated as detected; therefore, summary statistics can be calculated on the estimated TEQs even if most or all of the component congeners were undetected.

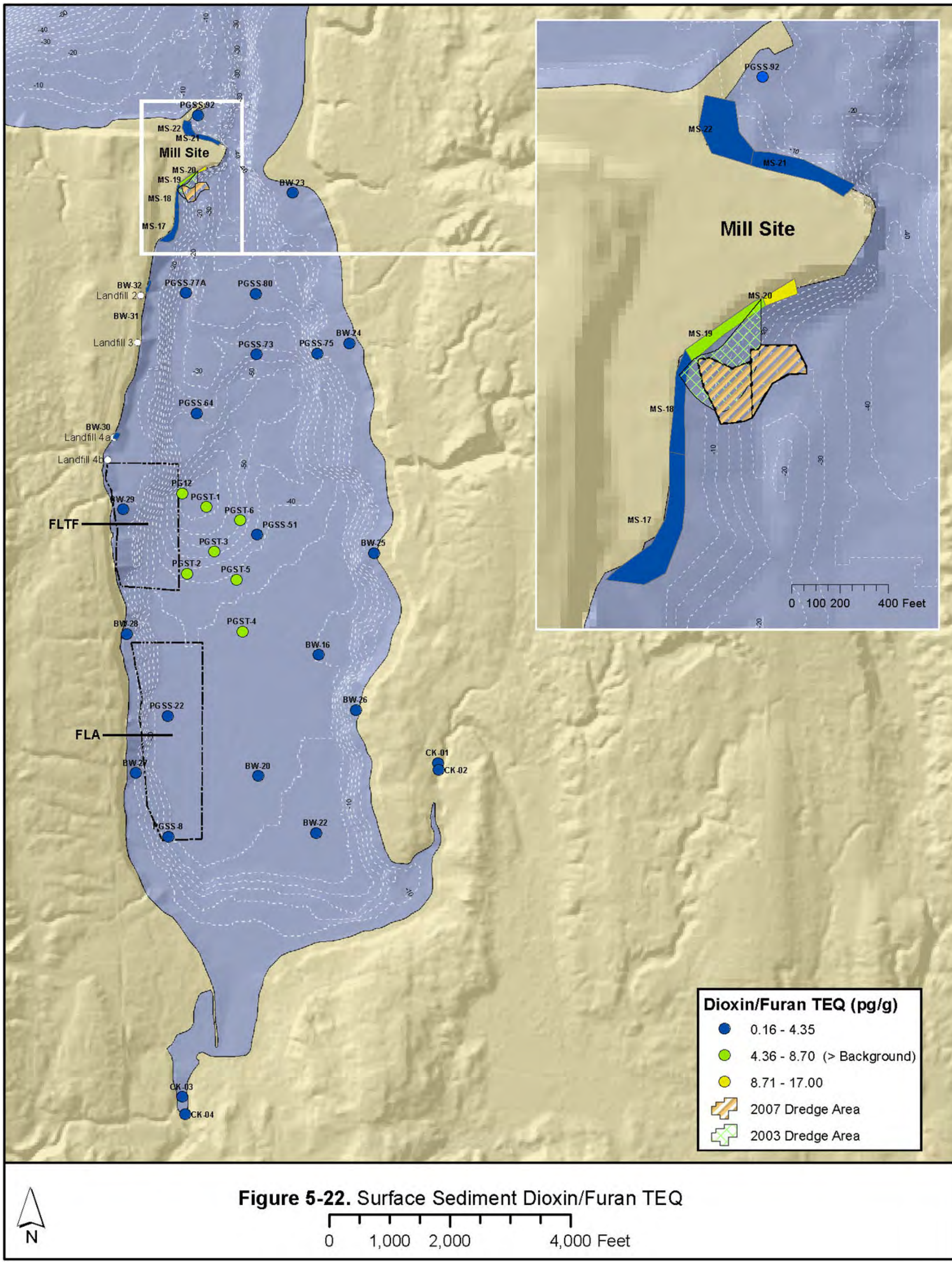


Figure 5-22. Surface Sediment Dioxin/Furan TEQ

Correlations between percent fines and the dioxin/furan TEQs were investigated in the same manner as for metals and PAHs. There were two extreme valued TEQs, found at intertidal station MS-20 and subtidal station MS-11. These stations had TEQ values nearly three times the next highest value. A scatterplot excluding these outliers (Figure 5-23) indicates that there is a fairly strong correlation among stations in the bay, and less so for stations near the mill.

Fingerprint analysis for dioxin/furan congeners involves determining the congener profile, which is the relative amount of each congener to the total dioxin/furan concentration for each sample. Congener profiles from a given site or study area are compared against each other to determine whether differences may exist as a result of unique sources. Individual congener profiles can also be compared to known source profiles as a means of determining the potential source of dioxin for a given area (Cleverly 1997). Table 5-13 shows the number of non-detected and estimated (J-qualified) congener concentrations present in the subtidal, intertidal, and reference data from Port Gamble.

Some of the congeners were rarely detected, including 2,3,7,8-TCDD and 1,2,3,7,8,9-HxCDF. Several other congeners were detected in about half of the samples, but estimated in the many of the remaining samples. From this table, only four congeners were detected in the majority of samples: 1,2,3,4,6,7,8-HpCDD, octachlorodibenzo-p-dioxin (OCDD), 1,2,3,4,6,7,8-HpCDF and octachlorodibenzofuran (OCDF). Unfortunately, this small number of detected congeners precluded the use of PCA as a statistical tool for this data set.

One option for the analysis of the Port Gamble data set was to create ratio cross plots similar to those used for the PAH source identification. Although such cross-plots have little precedent for use with dioxin/furan congeners, they offer two advantages with this data set: they allow all four of the selected congeners to be displayed in two dimensions, and they provide a quick visual screening for outliers or differences between the Port Gamble and reference data sets. Ratios were calculated as the concentrations of furans divided by dioxins for the hepta and octa congeners. As for the PAHs, these ratios were selected to minimize the impacts of weathering. OCDD and OCDF are both fully chlorinated, with 1,2,3,4,6,7,8-HpCDD and 1,2,3,4,6,7,8-HpCDF chlorinated in the same molecular positions. It was assumed that the congeners in each pair would weather at the same rates due to the similar positioning of the chlorine atoms, and thus any ratio differences would be due to differing sources. Ratios were calculated only when all four congeners were detected. As a result, seven samples were excluded, six intertidal and one subtidal (Table 5-13).

The top panel of Figure 5-24 shows the cross-plot ratios for all samples. Three samples are outliers: R_CAR_5 from the reference samples, PG11-MS-22-S from the intertidal samples, and PG-75 from the subtidal samples. There is no spatial or concentration pattern among these samples, so it is not clear why they were outliers.

The bottom panel of Figure 5-24 shows the cross plot ratios without the outliers. There was a high degree of overlap between the intertidal and subtidal samples from Port Gamble and moderate overlap between the reference sediment and that from Port Gamble. While the reference sediment may be slightly enriched in furans relative to dioxin, there is not a large enough distinction between the data sets to identify a significant difference in the dioxin/furan congener distributions between the Port Gamble and the reference data sets.

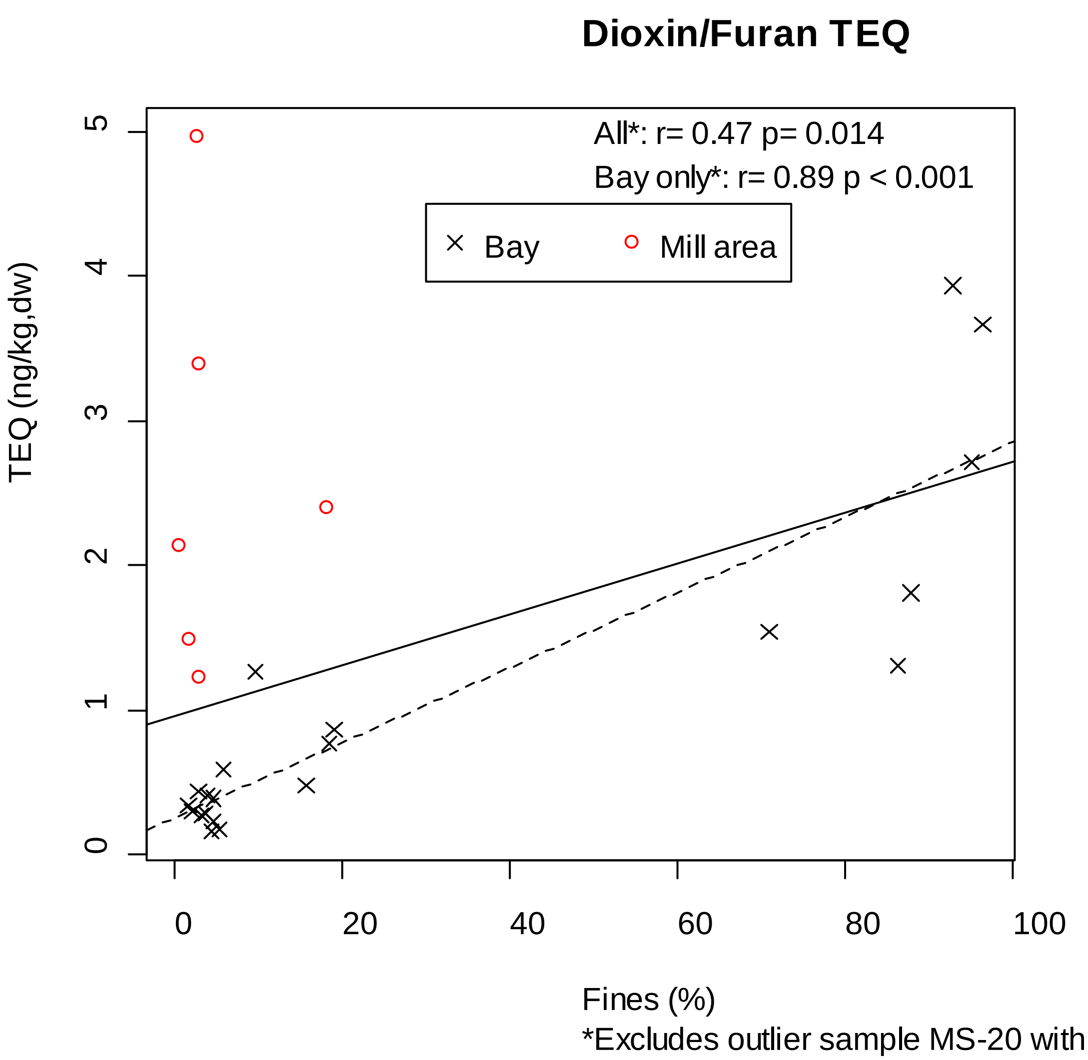


Figure 5-23. Correlations between Dioxin/Furan TEQ Values and the Fine-Grained Sediment Fraction. The best-fit regression line, the Pearson correlation coefficient (r), and its significance level (p) are shown. The solid line shows the best-fit regression line for all the data; the dashed line shows the best-fit regression line for the bay-only samples.

Table 5-13. Nondetected and Estimated Dioxin/Furan Congeners for Port Gamble Bay

	Intertidal		**Subtidal**		**Reference**		**Total**	
	N = 20		**N = 19**		**N = 14**		**N = 47**	
	ND	**Estimates**	**ND**	**Estimates**	**ND**	**Estimates**	**ND**	**Estimates**
2,3,7,8-TCDD	15	3	14	0	14	0	43	3
1,2,3,7,8-PeCDD	4	8	9	4	10	4	23	16
1,2,3,4,7,8-HxCDD	2	5	12	4	10	4	24	13
1,2,3,6,7,8-HxCDD	1	1	5	5	3	11	9	17
1,2,3,7,8,9-HxCDD	8	6	6	3	6	8	20	17
1,2,3,4,6,7,8-HpCDD	0	0	0	2	0	2	0	4
OCDD	0	0	0	0	0	1	0	1
2,3,7,8-TCDF	3	0	3	4	2	8	8	12
1,2,3,7,8-PeCDF	6	14	6	7	6	7	18	28
2,3,4,7,8-PeCDF	6	7	7	4	3	10	16	21
1,2,3,4,7,8-HxCDF	5	12	10	4	7	7	22	23
1,2,3,6,7,8-HxCDF	3	7	12	4	7	7	22	18
1,2,3,7,8,9-HxCDF	17	3	17	1	12	2	46	6
2,3,4,6,7,8-HxCDF	11	9	8	9	5	9	24	27
1,2,3,4,6,7,8-HpCDF	1	0	1	6	0	11	2	17
1,2,3,4,7,8,9-HpCDF	9	3	12	7	10	4	31	14
OCDF	6	2	1	5	0	11	7	18

ND: Non-detected concentration (U qualified)

Estimates: Detected below reporting limits (T or J qualified)

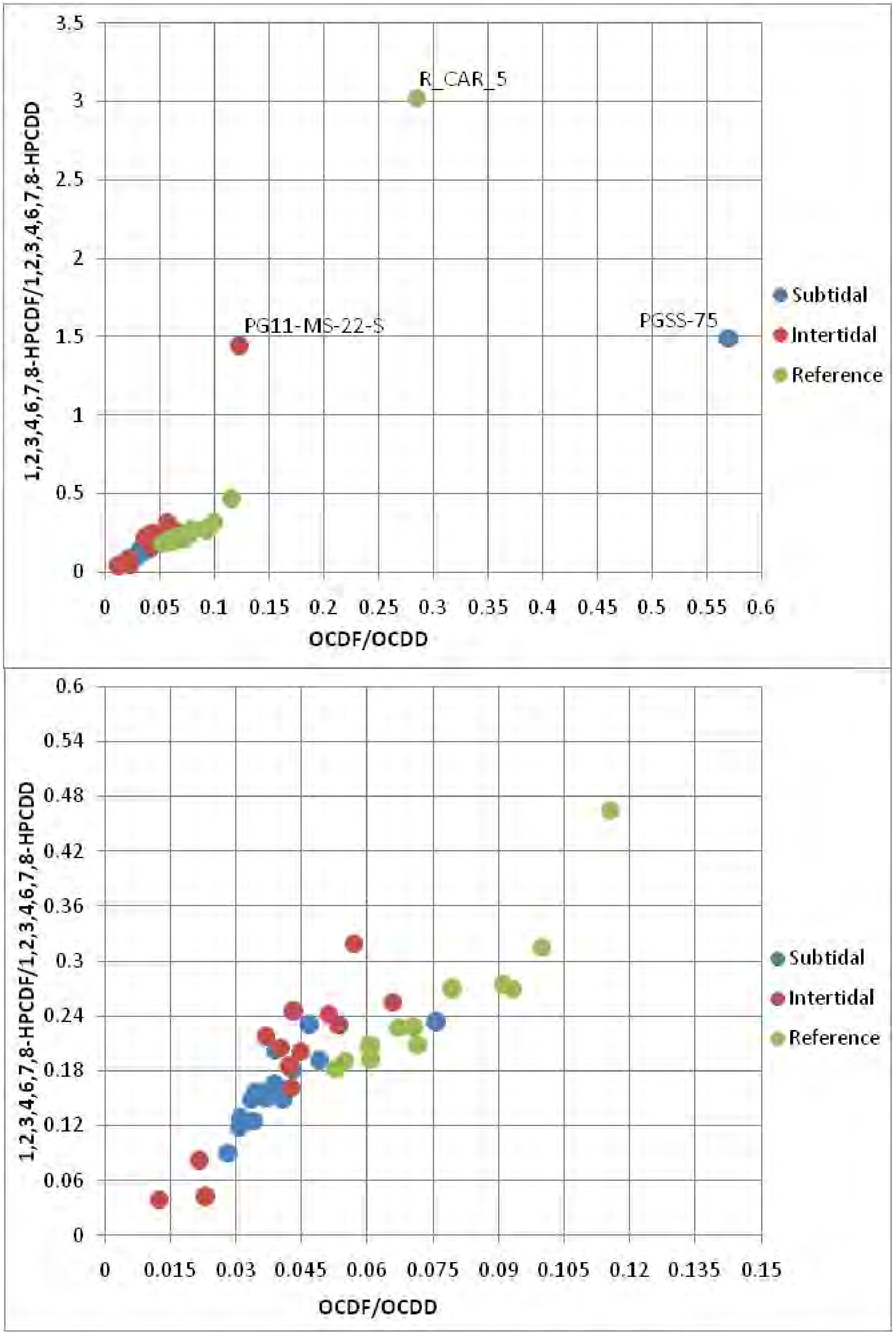


Figure 5-24. Cross-plot Ratios of Hepta Furan/Dioxin Ratio to Octa Furan/Dioxin Ratio

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6.0 TISSUE CHEMISTRY RESULTS

Sample locations for tissue testing results are shown in Figure 3-1. Numeric SMS standards are not available for protection of human health; instead, human health-based cleanup standards are calculated in Section 10 using these data and natural background concentrations. Contaminants in tissues exceeding natural background concentrations are shown in Figure 6-1 and Table 6-1.

6.1 Lipids

Percent lipids ranged widely in tissues from 0.208–6.9% wet weight (ww) (Table 6-2). The lowest lipids were typically found in Dungeness crab meat, as well as cockles, manila clams, and some littleneck clams. The highest lipids were found in Dungeness crab hepatopancreas, followed by oysters.

6.2 Metals

The metals discussed below are those that were considered potential contaminants of concern for human health (see Section 8). Summary concentrations for other metals can be found in Table 6-2 and for individual samples in Appendix A. In general, metals concentrations tended to vary with the percent lipids, with higher metals concentrations corresponding to higher lipid concentrations. In most cases, geographic differences were not as apparent as species differences. Unless otherwise noted, samples near the mill were similar to samples around other areas of the bay.

Arsenic was detected in most samples, except one oyster sample and all cockle samples, ranging from 1–8 mg/kg. The lowest concentrations were found in geoduck, oysters, manila clams, and cockles, and the highest concentrations were found in crab hepatopancreas.

Cadmium was detected in most samples, except two crab meat samples and several cockle samples, ranging from 0.04–1.49 mg/kg. The lowest concentrations were found in crab meat and cockles, while the highest concentrations were found in crab hepatopancreas and oysters.

Copper was detected in all tissue samples ranging from 0.91–19.2 mg/kg around the bay, and 1.86–33.5 near the former mill. The lowest concentrations were found in cockles, followed by littleneck and manila clams, and the highest concentrations were found in crab hepatopancreas and oysters.

Mercury was detected in most samples, except two littleneck clam and two cockle samples, ranging from 0.005–0.047 mg/kg. Lower concentrations were found in geoducks, oysters, and clams, while higher concentrations were found in crab meat and hepatopancreas.

6.3 Polynuclear Aromatic Hydrocarbons

At least one PAH was detected in most oysters and littleneck, manila, and cockle clam samples. PAHs were not detected in geoduck, crab meat, or hepatopancreas samples. In samples where PAHs were detected, cPAH TEQs ranged from 0.35–4.36 µg/kg around the bay, and 0.46–19.0 near the former mill (Table 6-2). The highest concentrations were found in littleneck clam samples near the former mill. Elevated concentrations of cPAH in tissue are generally colocated with areas of creosoted pilings.

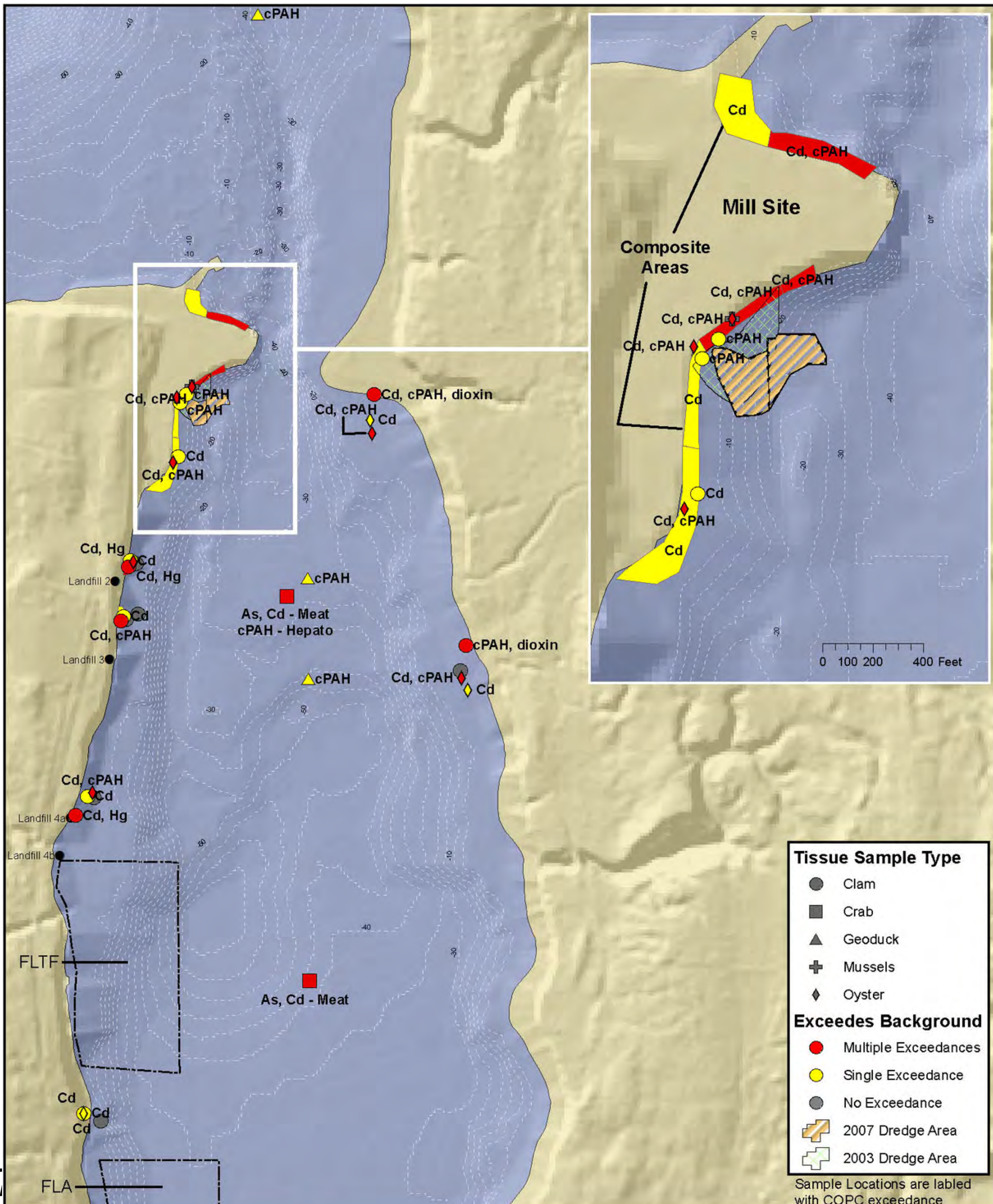

Figure 6-1. Tissue Chemistry Exceedances above Background

Table 6-1. Tissue Concentrations Exceeding Natural Background Concentrations

Sample ID	Organism	Tissue Type	Cadmium	Arsenic (Inorganic)	Mercury	cPAH TEQ	Dioxin/Furan
Maximum Natural Background			**0.26 µg/kg**	**0.62 µg/kg**	**0.014 µg/kg**	**1.3 µg/kg**	**0.27 ng/kg**
CLAM1A	Littleneck Clams	Whole	0.36	--	--	3.5	0.35
MS-17	Littleneck Clams	Whole	0.71	--	--	--	--
MS-18	Littleneck Clams	Whole	0.47	--	--	--	--
MS-19	Littleneck Clams	Whole	0.4	--	--	4.6	--
MS-20	Littleneck Clams	Whole	0.43	--	--	8.2	--
MS-21	Littleneck Clams	Whole	0.4	--	--	7.5	--
MS-22	Littleneck Clams	Whole	0.63	--	--	--	--
BW-30	Littleneck Clams	Whole	0.66	--	0.014	--	--
BW-31	Littleneck Clams	Whole	0.6	--	--	--	--
BW-32	Littleneck Clams	Whole	0.64	--	0.016	--	--
B1_L	Littleneck Clams	Whole	0.29	--	--	--	--
LF3_LN	Littleneck Clams	Whole	--	--	--	4.4	--
LF4_L	Littleneck Clams	Whole	0.37	--	--	--	--
LS_L	Littleneck Clams	Whole	0.45	--	--	--	--
CLAM2A	Littleneck Clams	Whole	--	--	--	3.5	0.37
LF2_M	Manila Clams	Whole	0.29	--	--	--	--
LF3_M	Manila Clams	Whole	0.27	--	--	2.7	--
LS_M	Manila Clams	Whole	0.35	--	--	--	--
B2_C	Cockles	Whole	--	--	--	1.9	--
B3_C	Cockles	Whole	--	--	--	1.7	--
OYSTER1A	Oyster†	Whole	0.99	--	--	3.5	0.37
OYSTER2A	Oyster†	Whole	0.96	--	--	3.5	0.37
B1_O	Oyster†	Whole	1.00	--	--	2.1	--
B2_O	Oyster†	Whole	1.27	--	--	9.5	--
B3_O	Oyster†	Whole	1.35	--	--	19.0	--
LF2_O	Oyster†	Whole	1.18	--	--	1.5	--
LF4_O	Oyster†	Whole	1.20	--	0.014	--	--
LS_O	Oyster†	Whole	1.28	--	--	--	--
PJ_O	Oyster†	Whole	1.13	--	--	--	--
RS1_O	Oyster†	Whole	1.23	--	--	--	--
SRS_O	Oyster†	Whole	1.49	--	--	--	--
Maximum Background			**0.34 µg/kg**	**0.62 µg/kg**	**0.042 µg/kg**	**0.17 µg/kg**	**1.4 ng/kg**
GD1A	Geoduck	Whole	--	--	--	3.4	--
GD2A	Geoduck	Whole	--	--	--	3.5	--
Maximum Background			**0.013 µg/kg**	**0.04 µg/kg**	**0.086 µg/kg**	**1.6 µg/kg**	**1.4 ng/kg**
CRAB1A	Dungeness	Edible Meat	0.04	0.14	--	3.5	--
BW-04*	Dungeness	Edible Meat	0.04	0.1	--	--	--
Maximum Background			**2.4 µg/kg**	**0.34 µg/kg**	**0.095 µg/kg**	**0.89 µg/kg**	**2.6 ng/kg**
CRAB1A	Dungeness	Hepato-pancreas	--	--	--	3.4	--

Maximum background = maximum concentration in natural background tissue data set (see Section 9).

*Average of 2 individuals. -- Did not exceed maximum background concentration.

†Oyster background data not available. Comparison made to clam values.

Non-detect with detection limit above maximum background concentration.

Table 6-2. Summary of Tissue Metals, PAHs, and PCB Results – Wet Weight

	Bay-wide Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Percent Lipids[a]												
Lipids	33	33	0.208	6.9	1.23	2.59	13	13	0.33	2.28	0.99	2.05
Metals in mg/kg ww												
Arsenic	33	27	1	8	2.55	5	13	9	1	5	2.08	3
Cadmium	33	28	0.04	1.49	0.496	1.2	13	13	0.04	1.35	0.545	1.22
Chromium	33	32	0.1	0.7	0.206	0.3	13	13	0.1	1.9	0.4	0.48
Copper	33	33	0.91	19.2	4.62	8.6	13	13	1.86	33.5	8.55	23
Lead	33	1	0.4	0.4	0.4	0.4	13	3	0.4	2	0.654	1.7
Silver	32	20	0.06	1.15	0.165	0.187	9	-1	0.06	0.3	0.107	0.18
Zinc	33	33	8.6	174	41.5	134	13	13	12.6	263	58.8	180
Mercury	33	29	0.005	0.047	0.0133	0.0278	13	10	0.005	0.012	0.00708	0.01
PCBs in µg/kg ww												
Aroclor 1016	26	0	3.9	8	4.89	8	7	0	3.9	4	3.96	4
Aroclor 1221	26	0	3.9	8	4.89	8	7	0	3.9	4	3.96	4
Aroclor 1232	26	0	3.9	8	4.97	8	7	0	3.9	6	4.53	5.94
Aroclor 1242	26	0	3.9	8	4.89	8	7	2	3.9	21	6.44	10.9
Aroclor 1248	26	0	3.9	12	5.12	8	7	1	3.9	7.2	4.41	5.28
Aroclor 1254	26	0	3.9	20	5.81	8.9	7	0	3.9	16	6.83	11.2
Aroclor 1260	26	1	3.9	15	5.16	8	7	0	3.9	4	3.96	4
Total PCBs	26	1	3.9	15	5.62	8.95	7	3	4	21	7.76	12.7
PAHs in µg/kg ww												
Benzo(a)anthracene	33	15	0.5	4.2	1.05	1.86	13	13	1	48	10.9	23.4
Benzo(a)pyrene	33	5	0.5	3.3	0.994	2	13	7	0.5	7.7	2.26	5
Benzo(b)fluoranthene	26	8	0.5	2.3	1.3	2.1	7	6	0.5	28	6.86	19
Benzo(k)fluoranthene	26	8	0.5	2.3	1.05	1.95	7	6	0.5	28	6.86	19
Benzofluoranthenes	33	8	0.14	4.6	1.46	3.52	13	12	0.5	56	9.72	23.2
Chrysene	33	15	0.5	4.5	1.43	3.68	13	12	0.5	62	11.8	34.8
Dibenz(a,h)anthracene	33	1	0.5	1.3	0.694	1.3	13	2	0.5	5	1.24	4.22
Indeno(1,2,3-cd)pyrene	33	2	0.5	1.3	0.614	0.83	13	2	0.5	5	1.26	4.26
c PAH TEQ	33	*	0.35	4.36	1.44	3.45	13	*	0.463	19.0	4.50	9.26

Non-detects included in descriptive statistics.

[a] Lipids were analyzed separately for both ARI samples (metals, PAH, PCB) and Axys samples (dioxin/furan and PCB congeners).

* TEQs shown in this table were calculated using the methods described in Section 8.2.4. Using this method, all TEQ values are treated as detected; therefore, summary statistics can be calculated for the TEQs even if most or all of the congeners were undetected.

6.4 Polychlorinated Biphenyls

PCB Aroclors were not detected in tissue samples, with the exception of Aroclor 1260 in one crab hepatopancreas sample from the bay at 15 μg/kg and Aroclor 1242 and 1248 from three samples near the mill ranging up to 21 μg/kg (Table 6-2). At least some PCB congeners were detected in all tissue samples in which they were analyzed, at TEQ concentrations ranging from 0.0215–1.65 ng/kg (Table 6-3). Geoduck, clam, oyster, and crab meat concentrations were relatively low, while crab hepatopancreas concentrations were highest.

6.5 Dioxins/Furans

At least one dioxin/furan congener was detected in most samples in which they were analyzed, with the exception of two littleneck clam samples, one crab meat sample, and both oyster samples (Table 6-3). Dioxin/furan TEQs in samples in which they were detected ranged from 0.077–2.22 (Figure 26). Concentrations were lowest in crab meat and some littleneck clam samples, and highest in crab hepatopancreas.

Table 6-3. Summary of Tissue Dioxin/Furan and PCB Congeners

	Bay-wide Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Percent Lipids[a]												
Lipids	15	15	0.208	7.79	1.88	5.36	6	6	1.18	1.6	1.41	1.53
Dioxin/Furan Congeners in ng/kg ww												
2,3,7,8-TCDD	15	1	0.0475	0.275	0.109	0.174	6	0	0.0475	0.055	0.0494	0.0525
1,2,3,7,8-PeCDD	15	3	0.0475	0.96	0.28	0.613	6	1	0.0475	0.05	0.0484	0.0493
1,2,3,4,7,8-HxCDD	15	2	0.0475	0.573	0.281	0.4	6	0	0.0475	0.056	0.0498	0.053
1,2,3,6,7,8-HxCDD	15	3	0.0475	2.45	0.568	1.54	6	3	0.0486	0.131	0.0879	0.123
1,2,3,7,8,9-HxCDD	15	2	0.0475	0.954	0.242	0.492	6	2	0.0478	0.207	0.0854	0.149
1,2,3,4,6,7,8-HpCDD	15	3	0.119	3.88	0.815	2.3	6	3	0.41	3.32	1.08	2.16
OCDD	15	9	0.224	4.13	1.57	3.02	6	6	2.23	26.3	8.81	19.3
2,3,7,8-TCDF	15	6	0.0475	1.85	0.392	1.36	6	0	0.0475	0.0506	0.0488	0.0503
1,2,3,7,8-PeCDF	15	2	0.0475	0.494	0.225	0.314	6	0	0.0475	0.05	0.0483	0.0493
2,3,4,7,8-PeCDF	15	4	0.0475	0.874	0.257	0.517	6	1	0.0475	0.059	0.0519	0.0585
1,2,3,4,7,8-HxCDF	15	1	0.0475	0.564	0.352	0.555	6	0	0.0475	0.05	0.0483	0.0493
1,2,3,6,7,8-HxCDF	15	2	0.0475	0.213	0.111	0.163	6	0	0.0475	0.05	0.0483	0.0493
1,2,3,7,8,9-HxCDF	15	0	0.047	0.261	0.155	0.256	6	0	0.0475	0.05	0.0483	0.0493
2,3,4,6,7,8-HxCDF	15	1	0.0475	0.308	0.199	0.303	6	0	0.0475	0.05	0.0483	0.0493
1,2,3,4,6,7,8-HpCDF	15	2	0.0484	0.935	0.417	0.685	6	0	0.056	0.205	0.117	0.188
1,2,3,4,7,8,9-HpCDF	15	0	0.047	0.584	0.319	0.574	6	0	0.0475	0.05	0.0483	0.0493
OCDF	15	0	0.0484	0.727	0.421	0.714	6	1	0.109	0.755	0.264	0.515
Dioxin TEQ	15	*	0.077	2.22	0.505	1.26	6	6	0.0804	0.140	0.103	0.136
PCBs Congeners in ng/kg ww												
PCB-077	15	9	0.523	37.1	7.82	29.6	6	6	0.405	3	1.71	2.72
PCB-081	15	0	0.145	1.69	0.762	1.24	6	0	0.186	0.32	0.238	0.308
PCB-105	15	15	3.09	802	167	598	6	6	4.87	43.4	28.5	43.2
PCB-114	15	7	0.35	44.2	8.94	33.5	6	4	0.253	2.68	1.56	2.56
PCB-118	15	15	8.05	2120	461	1680	6	6	13.2	109	70.6	109
PCB-123	15	8	0.324	40.2	7.86	29.6	6	4	0.278	2.1	1.34	2.02
PCB-126	15	2	0.203	15.8	2.52	6.95	6	0	0.245	0.392	0.293	0.348
PCB-156/157	15	13	1.76	429	74.7	266	6	6	3.19	19.9	13.5	19.5
PCB-167	15	13	0.879	188	36	133	6	6	1.53	8.08	5.54	8
PCB-169	15	0	0.163	3.33	0.974	2.2	6	0	0.151	0.245	0.204	0.236
PCB-189	15	7	0.612	46.9	7.18	25.4	6	5	0.358	2.3	1.4	2.09
PCB TEQ	15	*	0.0215	1.65	0.263	0.814	6	*	0.0255	0.0442	0.0336	0.0392

Table 6-3. Summary of Tissue Dioxin/Furan and PCB Congeners

Bay-wide Samples						Mill Area Samples					
Samples	Detects	Minimum	Maximum	Mean	90^{th} %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile

Non-detects included in descriptive statistics.

[a] Lipids were analyzed separately for both ARI samples (metals, PAH, PCB) and Axys samples (dioxin/furan and PCB congeners).

* TEQs shown in this table were calculated using the methods described in Section 8.2.4. Using this method, all TEQ values are treated as detected; therefore, summary statistics can be calculated for the TEQs even if most or all of the congeners were undetected.

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7.0 SEDIMENT BIOASSAY TESTING RESULTS

Sediment quality was evaluated based on biological criteria established in the SMS, which are used to identify areas with adverse biological effects. These criteria are based on both statistical significance (a statistical comparison to a reference station) and the degree of biological response (a numerical comparison to reference). Similar to the chemical criteria, the SMS establishes the SQS (a level at or below which no adverse effects are expected) and the CSL (a level at or below which only minor adverse effects are expected) criteria for evaluating sediment quality. The SQS is more stringent than the CSL and allows for less biological response in the test treatments.

Bioassay pass/fail test results relative to SQS and CSL criteria are based on a comparison of responses observed in the test sediment compared to those in the reference sediment. Reference and test sediments are matched based on sediment grain size with the recommended difference in percent fines between reference and test sediment being ≤20%.

The Microtox bioassay was performed as an exploratory test to evaluate its suitability as a rapid screening test for effects associated with wood waste. For SMS decision-making purposes, the Mill area and Port Gamble Bay RIs included a full suite of PSEP toxicity tests, including the 10-day amphipod survival test using *Eohaustorius estuarius*, the larval development test using either *Dendraster excentricus* or *Mytilus galloprovincialis*, and the chronic 20-day polychaete survival and growth test using *Neanthes arenaceodentata*. Laboratory results and sediment bioassay summaries from four sediment bioassay testing events are included in this RI (Anchor 2006a, 2009; Hart Crowser 2010; and NewFields 2011b). While there have been some bioassays conducted prior to these studies, they have been superseded by more recent data or the areas sampled have since been dredged.

The Mill Area RI in 2006 (Anchor 2006a) included a full suite of toxicity tests with sediment collected from 11 stations. Based on grain size, the following reference and test comparisons were made during the 2006 Mill Area RI:

- Reference sediment R1 (79.7% fines): Stations AS-01, 02, 03, 05, 07, 09, 13, 14, 3001, 3002, and 3004.

A supplemental remedial investigation (SRI) of the mill area was conducted in 2008 (Anchor 2009) using the amphipod test, the larval echinoderm test, and the Microtox test. None of the stations sampled were the same as the 2006 field investigation (Figure 3-1). Based on grain size, the following reference and test comparisons were made during the 2008 Mill Area SRI:

- Carr Inlet reference sediment CR-1 (55% fines): Stations AS-108, 113, and B14
- Carr Inlet reference sediment CR-22 (15% fines): AS-101, 102, 106, 112, B09, and B15
- Sequim Bay reference sediment SBREF35 (35% fines): AS-B11, B16, and B18

In 2009, Hart Crowser conducted an RI of Port Gamble Bay that included a full suite of toxicity tests conducted with sediment from 32 stations (Hart Crowser 2009). Based on similarity in grain size, the following reference and test sediment comparisons were performed during the 2009 Port Gamble Bay RI:

- Carr Inlet reference sediment CR20W (79.7% fines): Stations PGSS-8, 15, 16, 18, 20, 22, 30, 31, 33, 35, 39, 40, 42, 44, 45, 51, 53, 54, and 58.
- Carr Inlet reference sediment MSMP43 (6.4% fines): Stations PGSS-47, 56, 62, 67, 73, 75, 77A, and 92.
- Carr Inlet reference sediment CR23Mod (51.6% fines): Stations PGSS-21B, 29A, 38A, 63, and 64.

A supplementary investigation of Port Gamble Bay was conducted by NewFields in 2011 and included the juvenile polychaete test and the bivalve larval test. The following reference and test sediment comparisons were performed during the 2011 Port Gamble Bay Supplemental RI:

- Carr Inlet reference sediment CI-01 (6.1% fines): Stations BW-01, 02, 03, MS-02, 06, and 09.
- Carr Inlet reference sediment CI-02 (42.7% fines): Stations BW-07, 12, 17, MS-01, 03, 04, 05, 07, 08, and 10.
- Carr Inlet reference sediment CI-03 (77.7% fines): Stations BW-04, 05, 06, 08, 09, 10, 11, 13, 14, 15, 18, 19, 20, and 21.

7.1 Microtox Bioassay Results

7.1.1 Anchor Mill Area 2008 Supplemental RI

Microtox testing was included as a chronic test endpoint for the 2008 SRI of the mill area. A total of 13 stations were submitted for Microtox analysis. All treatments were between 97% and 121% of their respective reference, meeting both the SQS and CSL criteria (Table 7-1).

7.1.2 Hart Crowser 2008 RI

Fifty-two surface sediment samples and three reference samples were submitted to Nautilus Environmental for Microtox analyses. Six samples (PGSS-16, 62B, 51, 58, 63, and 69) exceeded the SQS criteria of mean test sediment light output <80% of reference and were statistically different from the reference (Table 7-2).

The laboratory noted that sample PGSS-16 had low salinity (9 ppt) and turbidity greater than 100 NTU. Due to the high turbidity, the transmission of light from the bacteria may have been inhibited and the result may be an artifact of the testing, not an indication of toxicity. This interpretation is supported by the observation that sample PGSS-16 passed the other bioassay tests.

Reference sample CR23MOD did not meet the acceptability criteria relative to the control sample in Test Batches 10 and 11, and the associated samples were subsequently compared to the control. Only one of these samples, PGSS-63, failed the comparison to the control, so it was designated an SQS level hit. However, sample PGSS-63 passed the other bioassay tests.

The Microtox bioassay was not found to be well correlated with indicators of the presence or toxicity of wood waste, unlike several of the other bioassays (Hart Crowser 2010). Therefore, it was not used in subsequent rounds of testing or for SMS decision making.

Table 7-1. Microtox Bioassay Results, Anchor 2008 Mill Area SRI

Station	Percent Fines	Reference	Change in Output at 5 min. (%)		Change in Output at 15 min. (%)		Sig. Diff.	SMS Interpretation LO_{Test} / LO_{Ref}	
			Mean	SD	Mean	SD		Value	SQS > 80%
Control			96	1	88	2	--	Pass QA (LO_f/LO_i > 80%)	
SBREF-35	35	Control[a]	99	4	95	5	No	108	Pass QA
AS-106	8.4	SBREF35[b]	98	1	93	5	No	97	Pass
AS-101	23.9	SBREF35	97	1	94	1	No	98	Pass
AS-112	12.8	SBREF35[b]	99	4	94	2	No	99	Pass
AS-B18	31.9	SBREF35	100	1	97	1	No	102	Pass
Control	--		92	2	83	2	--	Pass QA (LO_f/LO_i > 80%)	
SBREF-35	35	Control[a]	102	3	100	2	No	121	Pass QA
AS-B15	39.5	SBREF35	100	1	94	2	Yes	94	Pass
AS-B09	4.9	SBREF35[b]	101	1	98	3	No	98	Pass
AS-102	20.7	SBREF35	97	1	92	4	No	92	Pass
Control	--		96	4	88	7	--	Pass QA (LO_f/LO_i > 80%)	
CR-1	55	Control[a]	102	3	101	7	No	115	Pass QA
AS-108	23.9	CR-1	103	2	98	1	No	97	Pass
AS-113	44.0	CR-1	101	2	98	1	No	97	Pass
AS-B11	33.8	CR-1	102	4	100	5	No	99	Pass

[a] Reference treatments are compared to the control; performance standard is $LO_{F(Ref)}$ / $LO_{F(Control)}$ >80%.

[b] Alternative reference; no data for CR-22 – coarse grained sand, no porewater available for analysis.

Table 7-2. Microtox Bioassay Results, Hart Crowser 2008 RI

Station	Percent Fines	Reference	Change in Output at 5 min. (%)		Change in Output at 15 min. (%)		Sig. Diff	SMS Interpretation LO_{Test} / LO_{Ref}	
			Mean	SD	Mean	SD		Value	SQS > 80%
Control	--		96	4	91	4		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	101	1	99	3		99	Pass QA
PGSS-08	87.9	CR20W	102	5	98	6		99	Pass
PGSS-30	87.6	CR20W	99	1	92	2		93	Pass
PGSS-39	88.7	CR20W	100	1	93	2		94	Pass
PGSS-35	91.0	CR20W	103	2	98	3		99	Pass
Control	--		102	2	98	2		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	108	2	106	2		108	Pass QA
PGSS-20	93.6	CR20W	105	2	102	2		96	Pass
PGSS-15	92.7	CR20W	106	2	105	4		99	Pass
PGSS-40	84.1	CR20W	106	2	105	1		99	Pass
PGSS-22	92.2	CR20W	109	3	110	1		104	Pass
Control	--		97	1	91	2		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	104	2	102	3		112	Pass QA
PGSS-33	87.0	CR20W	100	2	96	4		94	Pass
PGSS-31	88.6	CR20W	102	2	98	4		96	Pass
PGSS-18	94.8	CR20W	101	1	95	2		93	Pass
PGSS-16	94.4	CR20W	76	3	74	4	Yes	73	Fail
Control	--		99	2	91	3		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	99	2	93	2		102	Pass QA
PGSS-14A	NA	MSMP43	99	1	93	2		100	Pass
PGSS-21A	NA	MSMP43	101	2	95	2		102	Pass
PGSS-29	NA	MSMP43	99	1	92	2		99	Pass
PGSS-46	NA	MSMP43	101	1	94	3		101	Pass
Control	--		96	1	83	1		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	97	1	88	1		106	Pass QA
PGSS-38	NA	MSMP43	99	2	89	4		101	Pass
PGSS-47	22.0	MSMP43	97	1	87	2		99	Pass
PGSS-56	12.6	MSMP43	98	2	85	3		97	Pass
PGSS-61	NA	MSMP43	98	2	88	2		100	Pass
Control	--		94	2	86	3		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	98	3	92	3		107	Pass QA
PGSS-62	6.7	MSMP43	96	4	88	5		96	Pass
PGSS-62A	NA	MSMP43	99	3	91	3		99	Pass
PGSS-62B	NA	MSMP43	55	5	49	4	Yes	53	Fail
PGSS-67	15.3	MSMP43	98	2	90	2		98	Pass
Control	--		100	5	98	4		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	106	7	106	11	No	91	Pass QA
PGSS-68	NA	CR20W	104	3	101	9	No	95	Pass
Control	--		96	4	89	3		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	96	5	92	4	No	103	Pass QA
PGSS-42	77.4	CR23MOD	100	2	93	3	No	101	Pass
PGSS-44	85.4	CR23MOD	102	2	96	4	No	104	Pass
PGSS-51	65.3	CR23MOD	56	3	47	2	Yes	51	Fail

Table 7-2. Microtox Bioassay Results, Hart Crowser 2008 RI

Station	Percent Fines	Reference	Change in Output at 5 min. (%)		Change in Output at 15 min. (%)		Sig. Diff	SMS Interpretation LO_{Test} / LO_{Ref}	
			Mean	SD	Mean	SD		Value	SQS > 80%
Control	--		96	1	86	1		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	95	5	91	3	No	106	Pass QA
PGSS-54	60.8	CR20W	103	1	95	3	No	104	Pass
PGSS-45	85.8	CR20W	80	3	73	3	No	80	Pass
PGSS-58	70.5	CR20W	67	2	61	2	Yes	67	Fail
PGSS-53	58.9	CR20W	103	3	93	2	No	102	Pass
Control	--		96	2	92	5		Pass QA (LO_f/LO_i > 80%)	
CR23MOD	51.6	Control[a]	48	1	43	2	Yes	47	Fail QA[b]
PGSS-55	NA	CR23MOD	102	1	100	1	No	109	Pass
PGSS-38A	52.4	CR23MOD	103	5	101	6	No	110	Pass
PGSS-77	NA	CR23MOD	104	1	102	2	No	111	Pass
PGSS-47A	NA	CR23MOD	102	5	99	6	No	108	Pass
Control	--		96	3	89	2		Pass QA (LO_f/LO_i > 80%)	
CR23MOD	51.6	Control[a]	55	3	49	3	Yes	55	Fail QA[b]
PGSS-64	23.2	CR23MOD	99	2	94	2	No	106	Pass
PGSS-63	21.8	CR23MOD	69	4	66	3	Yes	74	Fail
PGSS-21B	50.2	CR23MOD	102	1	96	2	No	108	Pass
PGSS-29A	69.9	CR23MOD	104	2	99	4	No	111	Pass
Control	--		95	2	91	1		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	97	3	95	4	No	104	Pass QA
PGSS-GEO3	NA	MSMP43	99	2	97	5	No	100	Pass
PGSS-82	NA	MSMP43	99	1	94	2	No	102	Pass
PGSS-69	NA	MSMP43	59	2	54	2	Yes	99	Fail
PGSS-71	NA	MSMP43	101	6	98	6	No	57	Pass
Control	--		95	2	88	3		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	100	7	97	9	No	110	Pass QA
PGSS-70	NA	MSMP43	97	1	90	1	No	93	Pass
PGSS-92	18.0	MSMP43	97	4	92	3	No	95	Pass
PGSS-80	NA	MSMP43	97	1	92	2	No	95	Pass
PGSS-77A	18.5	MSMP43	97	2	93	4	No	96	Pass
Control	--		94	4	87	5		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	97	4	93	4	No	107	Pass QA
PGSS-73	6.1	MSMP43	95	5	95	8	No	102	Pass
PGSS-78	NA	MSMP43	95	2	92	4	No	99	Pass
PGSS-83	NA	MSMP43	97	4	90	5	No	97	Pass
PGSS-75	3.9	MSMP43	95	3	87	2	No	94	Pass

[a] Reference treatments are compared to the control; performance standard is $LO_{F(Ref)} \div LO_{F(Control)}$ >80%.

[b] Test treatments compared to the control.

7.2 Amphipod Bioassay Results

The amphipod test provides an estimate of acute sediment toxicity and is based on the survival of burrowing amphipods exposed to test sediments relative to survival in the appropriate reference sediment. Under the SMS program, an amphipod bioassay test sample fails the SQS if the mean mortality is >25% higher than that of the reference sediment and the difference is statistically significant. Samples fail the CSL if the test sample mortality is >30% higher than that of the reference sediment and the difference is statistically significant.

Amphipod tests with *Eohaustorius estuarius* were conducted as part of three sediment investigations: the Mill Area RI (Anchor 2006a), the Mill Area SRI (Anchor 2009), and the Port Gamble Bay RI (Hart Crowser 2009).

7.2.1 Anchor 2006 Mill Area RI

A total of 11 sediment samples were evaluated for toxicity; eight samples were collected from the vicinity of the former mill and three samples were from the greater Port Gamble Bay. Mortality in the control and reference treatments was within acceptable limits (Table 7-3). With the exception of two samples in the embayment north of the former mill, all treatments pass both SQS and CSL criteria. Stations AS-01 and AS-03 failed the CSL criteria.

7.2.2 Anchor 2008 Mill Area Supplemental RI

The Mill Area SRI conducted in 2008 (Anchor 2009) collected sediment from 14 additional stations in the northern embayment and the area immediately south of the former mill. Mortality in the control and reference treatments met the quality control limits for the amphipod test (Table 7-3). All 14 treatments passed both the SQS and CSL criteria, with mortality ranging from 3 to 11%.

7.2.3 Hart Crowser 2008 RI

All 32 amphipod test results passed the SQS criteria (Table 7-4). While 17 of the test samples had mortality significantly higher than the associated reference sediment samples, the percent difference between the test and reference survival was less than the 25% threshold.

Table 7-3. Amphipod Bioassay Results for *Eohaustorius estuarius*, Anchor 2006/2008 Mill Area RI/SRI

Station	Percent Fines	Reference	Percent Mortality		Sig. Diff.	SMS Interpretation M_{Test} - M_{Ref}		
			Mean	SD		Value	SQS >25%	CSL >30%
Control	--		7.0	4.5			Pass QA (M < 10%)	
AS-R1	15.3	Control[a]	13.0	4.5	--	--	Pass QA[a]	
AS-R3	39.7	Control[a]	6.0	8.9	--	--	Pass QA[a]	
AS-01	23.9	R1	47.0	39.1	Yes	34	Fail	Fail
AS-02	20.7	R1	31.0	22.5	Yes	18	Pass	Pass
AS-03	14.7	R1	72.0	39.5	Yes	59	Fail	Fail
AS-05	50.1	R3	12.0	12.5	No	6	Pass	Pass
AS-07	42.6	R3	10.0	5.0	No	4	Pass	Pass
AS-09	26.1	R1	12.0	4.5	No	-1	Pass	Pass
AS-13	17.6	R1	5.0	5.0	No	-6	Pass	Pass
AS-14	6.7	R1	11.0	5.5	No	-2	Pass	Pass
AS-3001	54.7	R3	10.0	5.0	No	4	Pass	Pass
AS-3002	83.5	R3	15.0	9.4	Yes	9	Pass	Pass
AS-3004	83.8	R3	22.0	43.7	No	16	Pass	Pass
Control	--		10.0	6.1			Pass QA (M < 10%)	
CR-1	55	Control[a]	16.0	6.5	--	--	Pass QA[a]	
CR-22	15	Control[a]	7.0	4.5	--	--	Pass QA[a]	
SBR-35	35	Control[a]	10.0	10.6	--	--	Pass QA[a]	
AS-101	7.7	CR-22	11.0	8.9	No	4	Pass	Pass
AS-102	6.2	CR-22	11.0	4.2	No	4	Pass	Pass
AS-106	8.4	CR-22	4.0	4.2	No	-3	Pass	Pass
AS-108	46.2	CR-1	5.0	5.0	No	-2	Pass	Pass
AS-112	12.8	CR-22	3.0	2.7	No	-4	Pass	Pass
AS-113	44.0	CR-1	10.0	5.0	No	-5	Pass	Pass
AS-B09	4.9	CR-22	7.0	5.7	No	0	Pass	Pass
AS-B11	33.7	SBR-35	10.0	5.0	No	0	Pass	Pass
AS-B14	57.8	CR-1	6.0	8.2	No	-10	Pass	Pass
AS-B15	ND	CR-22	6.0	4.2	No	-1	Pass	Pass
AS-B16	26.7	SBR-35	7.5	6.1	No	-2.5	Pass	Pass
AS-B18	32.0	SBR-35	6.0	6.5	No	-4	Pass	Pass

[a] Reference treatments are compared to the control; Performance standard is $M_{Ref} - M_{Control} \leq 20\%$.

[b] No available data; comparison made based on RI/FS (Anchor 2009).

Table 7-4. Amphipod Bioassay Results for *Eohaustorius estuarius*, Hart Crowser 2008 RI

Station	Percent Fines	Reference	Percent Mortality		Sig. Diff.	SMS Interpretation M_{Test} - M_{Ref}		
			Mean	SD		Value	SQS >25%	CSL >30%
Batch 1								
Control	--		0.0	0.0			Pass QA (M < 10%)	
MSMP43	6.4	Control[a]	1.0	2.2	--	--	Pass QA[a]	
CR20W	79.7	Control[a]	1.0	2.2	--	--	Pass QA[a]	
CR23 MOD	51.6	Control[a]	1.0	2.2	--	--	Pass QA[a]	
PGSS-08	87.9	CR20W	4.0	2.2	Yes	3	Pass	Pass
PGSS-15	92.7	CR20W	13.0	11.0	Yes	12	Pass	Pass
PGSS-16	94.4	CR20W	3.0	6.7	No	2	Pass	Pass
PGSS-18	94.8	CR20W	18.0	24.1	Yes	17	Pass	Pass
PGSS-20	93.6	CR20W	11.0	5.5	Yes	10	Pass	Pass
PGSS-21B	50.2	CR23MOD	2.0	2.7	No	1	Pass	Pass
PGSS-22	92.2	CR20W	3.0	6.7	No	2	Pass	Pass
PGSS-29A	69.9	CR20W	8.0	6.7	Yes	7	Pass	Pass
PGSS-30	87.6	CR20W	12.0	7.6	Yes	11	Pass	Pass
PGSS-31	88.6	CR20W	10.0	9.4	Yes	9	Pass	Pass
PGSS-33	87.0	CR20W	4.0	4.2	No	3	Pass	Pass
PGSS-35	91.0	CR20W	8.0	5.7	Yes	7	Pass	Pass
PGSS-38A	52.4	CR23MOD	10.0	3.5	Yes	9	Pass	Pass
PGSS-39	88.7	CR20W	11.0	6.5	Yes	10	Pass	Pass
PGSS-40	84.1	CR20W	5.0	5.0	No	4	Pass	Pass
PGSS-42	77.4	CR20W	16.0	12.9	Yes	15	Pass	Pass
Batch 2								
Control			3.0	4.5			Pass QA (M < 10%)	
MSMP43	6.4	Control[a]	2.0	2.7	--	--	Pass QA[a]	
CR20W	79.7	Control[a]	2.0	2.7	--	--	Pass QA[a]	
CR23 MOD	51.6	Control[a]	2.0	2.7	--	--	Pass QA[a]	
PGSS-44	85.4	CR20W	12.0	7.6	Yes	10	Pass	Pass
PGSS-45	85.8	CR20W	18.0	18.9	Yes	16	Pass	Pass
PGSS-47	22	MSMP43	4.0	4.2	No	2	Pass	Pass
PGSS-51	65.3	CR23MOD	9.0	10.8	No	7	Pass	Pass
PGSS-53	58.9	CR23MOD	10.0	7.9	Yes	8	Pass	Pass
PGSS-54	60.8	CR23MOD	19.0	6.5	Yes	17	Pass	Pass
PGSS-56	12.6	MSMP43	4.0	4.2	No	2	Pass	Pass
PGSS-58	70.5	CR20W	3.0	4.5	No	1	Pass	Pass
PGSS-62	6.7	MSMP43	2.0	4.5	No	0	Pass	Pass
PGSS-63	21.8	MSMP43	10.0	7.9	Yes	8	Pass	Pass
PGSS-64	23.2	MSMP43	6.0	6.5	No	4	Pass	Pass
PGSS-67	15.3	MSMP43	8.0	6.7	No	6	Pass	Pass
PGSS-73	6.1	MSMP43	2.0	2.7	No	0	Pass	Pass
PGSS-75	3.9	MSMP43	1.0	2.2	No	-1	Pass	Pass
PGSS-77A	18.5	MSMP43	13.0	10.4	Yes	11	Pass	Pass
PGSS-92	18	MSMP43	5.0	5.0	No	3	Pass	Pass

[a] Reference treatments are compared to the control; performance standard is $M_{Ref} - M_{Control} \leq 20\%$.

7.3 Juvenile Polychaete Bioassay Results

The juvenile polychaete test provides an estimate of chronic toxicity and is based on mean individual growth (MIG) in the test treatments relative to the MIG in the appropriate reference over a period of 20 days. MIG is expressed as mg biomass per individual per day. A bioassay sample fails the SQS if the MIG in the test sediment is <70% of that in the reference and the difference is statistically significant. A sample fails the CSL if the MIG is <50% of the reference and is statistically different. The juvenile polychaete test was included in three sediment investigations, the Mill Area RI (Anchor 2006a) and the Port Gamble Bay RI (Hart Crowser 2009) and SRI (NewFields 2011b).

7.3.1 Anchor 2006 Mill Area RI

Control and reference survival and growth met quality criteria for test samples evaluated in the 2006 Mill Area RI (Table 7-5). Mean individual growth for all samples passed the CSL criterion; however, MIG in four samples (AS-02, 05, AS-3001, and AS-3004) was below the SQS criterion when compared to the appropriate reference.

Table 7-5. Polychaete Bioassay Results for *Neanthes arenaceodentata*, Anchor 2006 Mill Area RI

Station	Percent Fines	Reference	Mean Individual Growth		Sig. Diff.	SMS Interpretation MIG_{Test} / MIG_{Ref}			Sample Retested
			Mean	SD		Value	SQS <70%	CSL <50%	
Control	--		0.70	0.13			Pass QA (MIG > 0.38)		
R1	15.3	Control[a]	0.66	0.11	--	0.94	Pass QA[a]		
R3	39.7	Control[a]	0.56	0.09	--	0.80	Pass QA[a]		
AS-01	23.9	R1	0.50	0.10	Yes	76	Pass	Pass	MS-01
AS-02	20.7	R1	0.45	0.11	Yes	68	Fail	Pass	
AS-03	14.7	R1	0.47	0.15	Yes	71	Pass	Pass	MS-03
AS-05	50.1	R3	0.35	0.15	Yes	62	Fail	Pass	MS-04
AS-07	42.6	R3	0.50	0.08	No	89	Pass	Pass	
AS-09	26.1	R1	0.53	0.07	Yes	80	Pass	Pass	
AS-13	17.6	R1	0.55	0.15	No	83	Pass	Pass	
AS-14	6.7	R1	0.55	0.10	No	83	Pass	Pass	
AS-3001	54.7	R3	0.45	0.10	No	80	Pass	Pass	
AS-3002	83.5	R3	0.52	0.10	No	93	Pass	Pass	
AS-3004	83.8	R3	0.34	0.08	Yes	61	Fail	Pass	PGSS-08

[a] Reference treatments are compared to the control; performance standard is MIG_{Ref} / $MIG_{Control}$ ≥ 0.80.

[b] Test treatments were compared to both an alternative reference and the control; results are presented for both comparisons.

7.3.2 Hart Crowser 2008 RI

Control survival and growth met quality criteria for both batches of test samples evaluated in the 2009 Port Gamble Bay RI (Table 7-6). With the exception of the fine-grained reference (CR-20W) in the first test batch, all references met the reference sediment performance standards. The growth rate for reference CR-20W in Batch 1 was 71.2% of the control, below the 80% performance criterion. While SMS does not provide explicit guidance when reference samples fail performance criteria, for the purposes of the 2009 RI, fine grain-sized sediments were compared to both the control and the medium grain-size reference (CR-23 MOD). The control represented the most conservative point of reference. Reference CR-23 MOD represented the next most similar grain size reference with acceptable growth.

Growth rates were statistically lower than the corresponding references or controls for nine of the 32 test sediments (Table 7-6). All test samples passed the CSL criterion with growth that was greater than 50% of the references or control. With the exception of five samples, all stations met the SQS criterion with growth greater than 70% of the reference or control. Samples PGSS-18, 30, 33, 39, and 40 failed the SQS performance standard for growth when compared to the control. However, when compared to the alternate medium grain-size reference (CR-23 MOD), only sample PGSS-30 failed the SQS criterion.

The cause of the SQS failures at these stations was further investigated as part of the Port Gamble Bay SRI. Because juvenile worm biomass is very small and the mass of ingested sediment can be relatively high, the ingested sediment can affect the outcome of sediment comparisons. This is particularly true when comparing fine-grained sediments to coarse sands. Recent studies have indicated that as much as 50% of the biomass in worms exposed to a sand control can be due to the sediment in the gut, whereas for fine-grained references, the range is 19–34% (NewFields 2010c, 2011c). Sibley et al. (1997) found similar sources of variation associated with different types of sediment retained in the guts of *Chironomus* sp. larvae. To correctly compare between dissimilar sediments, AFDW is used as a biomass endpoint. AFDW subtracts out the sediment weight and is purely a comparison of tissue biomass. AFDW is the standard measure for biomass for other nationally recognized test protocols for organisms that ingest sediment, such as *Chironomus* sp. (Sibley et al. 1997; EPA 2000). Those stations that were associated with the reference failure during the 2009 RI were therefore rerun with AFDW used to calculate MIG (Table 7-7).

Table 7-6. Polychaete Bioassay Results for *Neanthes arenaceodentata*, Hart Crowser 2008 RI

Station	Percent Fines	Reference	Mean Individual Growth		Sig. Diff.	SMS Interpretation MIG_{Test} / MIG_{Ref}			Sample Tested in SRI
			Mean	SD		Value	SQS <70%	CSL <50%	
Batch 1									
Control	--		1.04	0.0			Pass QA (MIG > 0.38)		
MSMP43	6.4	Control[a]	0.92	0.21	--	0.88	Pass QA[a]		•
CR20W	79.7	Control[a]	0.74	0.26	--	0.71	Fails QA[a]		•
CR23 MOD	51.6	Control[a]	0.91	0.21	--	0.84	Pass QA[a]		•
PGSS-08	87.9	CR23/Control[b]	1.00	0.09	No	1.10/0.96	Pass	Pass	
PGSS-15	92.7	CR23/Control[b]	0.78	0.21	No	0.86/0.75	Pass	Pass	
PGSS-16	94.4	CR23/Control[b]	0.84	0.10	No	0.92/0.81	Pass	Pass	
PGSS-18	94.8	CR23/Control[b]	0.70	0.12	No/Yes	0.77/0.67	Pass/Fail	Pass	BW-20
PGSS-20	93.6	CR23/Control[b]	0.82	0.18	No	0.90/0.79	Pass	Pass	
PGSS-21B	50.2	CR23	0.73	0.12	No	0.80	Pass	Pass	
PGSS-22	92.2	CR23/Control[b]	0.89	0.17	No	0.98/0.86	Pass	Pass	
PGSS-29A	69.9	CR23	0.77	0.15	No	0.85	Pass	Pass	
PGSS-30	87.6	CR23/Control[b]	0.62	0.18	Yes/Yes	0.68/0.60	Fail/Fail	Pass	BW-13
PGSS-31	88.6	CR23/Control[b]	0.79	0.07	No	0.87/0.76	Pass	Pass	
PGSS-33	87.0	CR23/Control[b]	0.68	0.20	No/Yes	0.75/0.65	Pass/Fail	Pass	BW-15
PGSS-35	91.0	CR23/Control[b]	0.85	0.06	No	0.93/0.82	Pass	Pass	
PGSS-38A	52.4	CR23	0.75	0.24	No	0.82	Pass	Pass	
PGSS-39	88.7	CR23/Control[b]	0.71	0.16	No/Yes	0.78/0.68	Pass/Fail	Pass	BW-08
PGSS-40	84.1	CR23/Control[b]	0.65	0.10	No/Yes	0.71/0.63	Pass/Fail	Pass	BW-09
PGSS-42	77.4	CR23/Control[b]	0.77	0.15	No	0.85/0.74	Pass	Pass	
Batch 2									
Control	--		1.04	4.5			Pass QA (MIG > 0.38)		
MSMP43	6.4	Control[a]	0.86	0.16	--	0.82	Pass QA[a]		
CR20W	79.7	Control[a]	1.06	0.18	--	1.02	Pass QA[a]		
CR23 MOD	51.6	Control[a]	0.99	0.12	--	0.95	Pass QA[a]		
PGSS-44	85.4	CR20W	0.77	0.14	Yes	0.73	Pass	Pass	
PGSS-45	85.8	CR20W	0.89	0.09	Yes	0.84	Pass	Pass	
PGSS-47	22.0	MSMP43	0.93	0.21	No	1.08	Pass	Pass	
PGSS-51	65.3	CR23MOD	0.88	0.11	No	0.89	Pass	Pass	
PGSS-53	58.9	CR23MOD	0.84	0.13	No	0.85	Pass	Pass	
PGSS-54	60.8	CR23MOD	0.81	0.12	Yes	0.82	Pass	Pass	
PGSS-56	12.6	MSMP43	1.01	0.26	No	1.17	Pass	Pass	
PGSS-58	70.5	CR20W	0.83	0.20	Yes	0.84	Pass	Pass	
PGSS-62	6.7	MSMP43	1.03	0.13	No	1.20	Pass	Pass	
PGSS-63	21.8	MSMP43	0.84	0.12	No	0.98	Pass	Pass	
PGSS-64	23.2	MSMP43	0.83	0.22	No	0.97	Pass	Pass	
PGSS-67	15.3	MSMP43	0.94	0.19	No	1.09	Pass	Pass	
PGSS-73	6.1	MSMP43	1.01	0.21	No	1.17	Pass	Pass	
PGSS-75	3.9	MSMP43	0.91	0.12	No	1.06	Pass	Pass	
PGSS-77A	18.5	MSMP43	0.78	0.06	No	0.91	Pass	Pass	
PGSS-92	18.0	MSMP43	0.89	0.07	No	1.03	Pass	Pass	

[a] Reference treatments are compared to the control; performance standard is MIG_{Ref} / $MIG_{Control}$ ≥ 0.80.

[b] Test treatments were compared to both an alternative reference and the control; results are presented for both comparisons.

Table 7-7. Polychaete Bioassay Results for *Neanthes arenaceodentata*, NewFields 2011 RI

2011 SRI Station	2009 RI Station	Percent Fines	Reference	Mean Individual Growth mg/ind/day Dry Weight						Mean Individual Growth mg/ind/day Ash-Free Dry Weight					
				Mean	SD	Sig. Diff.	SMS Interpretation MIG_{Test} / MIG_{Ref}			Mean	SD	Sig. Diff.	SMS Interpretation MIG_{Test} / MIG_{Ref}		
							Value	SQS <0.70	CSL <0.50				Value	SQS <0.70	CSL <0.50
Control				0.61	0.04		Pass QA (MIG > 0.38)			0.48	0.06		Pass QA (MIG > 0.38)		
CI-01	--	6.1	Control[a]	0.57	0.08	--	0.93	Pass QA[a]		0.45	0.04	--	0.93	Pass QA[a]	
CI-02	--	42.7	Control[a]	0.66	0.17	--	1.08	Pass QA[a]		0.52	0.15	--	1.08	Pass QA[a]	
CI-03	--	77.7	Control[a]	0.66	0.05	--	1.08	Pass QA[a]		0.53	0.05	--	1.08	Pass QA[a]	
MS-02	AS-104	18.0	CI-01	0.50	0.20	No	0.88	Pass	Pass	0.42	0.17	No	0.92	Pass	Pass
MS-04	AS-05	55.8	CI-02	0.55	0.06	No	0.84	Pass	Pass	0.47	0.05	No	0.91	Pass	Pass
MS-05	NA	17.1	CI-01	0.59	0.13	No	1.04	Pass	Pass	0.55	0.18	No	1.22	Pass	Pass
MS-09	NA	16.3	CI-01	0.41	0.09	Yes	0.72	Pass	Pass	0.36	0.09	Yes	0.79	Pass	Pass
MS-10	AS-B16	38.5	CI-02	0.52	0.14	No	0.79	Pass	Pass	0.46	0.12	No	0.89	Pass	Pass
BW-08	PGSS-39	88.2	CI-03	0.60	0.10	No	0.90	Pass	Pass	0.49	0.09	No	0.92	Pass	Pass
BW-09	PGSS-40	86.4	CI-03	0.61	0.03	Yes	0.92	Pass	Pass	0.50	0.03	No	0.95	Pass	Pass
BW-13	PGSS-30	87.2	CI-03	0.65	0.06	No	0.98	Pass	Pass	0.53	0.05	No	0.99	Pass	Pass
BW-15	PGSS-33	90	CI-03	0.64	0.03	No	0.96	Pass	Pass	0.52	0.03	No	0.99	Pass	Pass
BW-19	NA	95.3	CI-03	0.62	0.05	No	0.94	Pass	Pass	0.51	0.05	No	0.96	Pass	Pass
BW-20	PGSS-18	96.5	CI-03	0.61	0.07	No	0.92	Pass	Pass	0.51	0.06	No	0.96	Pass	Pass
BW-21	NA	95.3	CI-03	0.60	0.04	Yes	0.90	Pass	Pass	0.51	0.03	No	0.96	Pass	Pass

[a] Reference treatments are compared to the control; performance standard is MIG_{Ref} / $MIG_{Control} \geq 0.80$.

7.3.3 NewFields 2011 RI

To refine the estimates of toxicity at those stations with reference failures, the juvenile polychaete growth test was retested for Stations PGSS-18, 30, 33, 39, and 40 in the bay, as well as Stations AS-05, 104, and B16 from the vicinity of the former mill. In addition, two new stations in the vicinity of Station PGSS-18 were tested to better characterize this portion of the lower bay. Two new stations in the mill area (MS-05 and 08) were included to better characterize the area near the former log yard.

Control survival and growth met quality criteria for the juvenile polychaete test (Table 7-7). Survival and growth in each of the references met the survival and growth criteria, with growth that was 93–108% of the control. Growth rates were statistically lower than the corresponding references or controls for 3 of the 12 test sediments. All test samples passed the both the SQS and CSL criteria, with growth that was greater than 72% of the corresponding references for both dry weight and AFDW.

7.4 Larval Bioassay Results

For the larval test, benthic toxicity is evaluated based on the average number of normal larvae that are recovered in the test treatments relative to the number of normal larvae that are recovered from the appropriate reference sediment. A bioassay sample fails the SQS if mean normal survivorship is <85% of the reference sediment and the difference is statistically significant. A bioassay sample fails the CSL if normal survivorship is <70% of the reference sediment and the difference is statistically significant. Larval toxicity tests were included in the Mill Area RI (Anchor 2006a) and SRI (Anchor 2009) and the Port Gamble Bay RI (Hart Crowser 2009) and SRI (NewFields 2011b).

7.4.1 Anchor 2006 Mill Area RI

In 2006, 11 sediment samples were tested for acute toxicity using the larval echinoderm, *Dendraster excentricus*. Normal development in both the control and the R1 reference sample met the SMS acceptability criterion (65% of control; Table 7-8). The reference, AS-R3, had 50% normal survival relative to the control and was not considered acceptable for interpretation of test sediments. The reference AS-R1 was therefore used to evaluate all test sediments.

With the exception of Station AS-3002, all stations failed the SQS criterion for the larval test with less than 85% normal survival relative to the reference. Sediment from Stations AS-03, 14, 3001, and 3004 also failed the CSL criterion with less than 70% normal survival relative to the reference.

7.4.2 Anchor 2008 Mill Area Supplemental RI

The Mill Area SRI included 14 additional stations in the vicinity of the former Pope and Talbot Mill. None of the stations directly replaced stations collected during the 2006 RI. Normal survivorship in the control and reference treatments met the SMS acceptability criteria (Table 7-8). A total of 10 stations failed the SQS criterion with less than 85% normal survivorship relative to the reference. Two stations in the embayment immediately south of the mill (AS-B11 and B14) had normal survivorship below the CSL criterion of 70% relative to the reference.

Table 7-8. Larval Bioassay Results for *Dendraster excentricus*, Anchor 2006/2008 Mill Area RI/SRI

Station	Percent Fines	Reference	Number Normal		Sig. Diff.	SMS Interpretation N_{Test} / N_{Ref}			Sample Tested in SRI
			Mean	SD		Value	SQS <0.85	CSL <0.70	
2006 Mill Area Remedial Investigation									
Control	--		354	19			Pass QA (N > 70%)		
AS-R1	15.3	Control[a]	298	53	--	0.84	Pass QA[a]		
AS-R3	39.7	Control[a]	178	35	--	0.50	Fails QA[a]		
AS-01	23.9	AS-R1	216	22	Yes	0.72	Fail	Pass	MS-01
AS-02	20.7	AS-R1	235	57	Yes	0.79	Fail	Pass	
AS-03	14.7	AS-R1	183	57	Yes	0.61	Fail	Fail	MS-03
AS-05	50.1	AS-R1[b]	224	37	Yes	0.75	Fail	Pass	MS-04
AS-07	42.6	AS-R1[b]	214	72	Yes	0.72	Fail	Pass	
AS-09	26.1	AS-R1	215	41	Yes	0.72	Fail	Pass	
AS-13	17.6	AS-R1	237	60	Yes	0.80	Fail	Pass	
AS-14	6.7	AS-R1	205	55	Yes	0.69	Fail	Fail	MS-08
AS-3001	54.7	AS-R1[b]	143	37	Yes	0.48	Fail	Fail	BW-12
AS-3002	83.5	AS-R1[b]	254	16	No	0.85	Pass	Pass	
AS-3004	83.9	AS-R1[b]	172	51	Yes	0.58	Fail	Fail	PGSS-8
2008 Mill Area Supplemental Remedial Investigation									
Control	--		231	14			Pass QA (N > 70%)		
CR-1	55	Control[a]	214	15	--	0.93	Pass QA[a]		
CR-22	15	Control[a]	221	7	--	0.96	Pass QA[a]		
SBR-35	35	Control[a]	210	8	--	0.91	Pass QA[a]		
AS-101	7.7	CR-22	190	21	Yes	0.86	Pass	Pass	
AS-102	6.2	CR-22	189	17	Yes	0.86	Pass	Pass	
AS-106	8.4	CR-22	162	11	Yes	0.73	Fail	Pass	
AS-108	46.2	CR-1	227	6	No	1.06	Pass	Pass	
AS-112	12.8	CR-22	169	11	Yes	0.76	Fail	Pass	
AS-113	44.0	CR-1	170	20	Yes	0.79	Fail	Pass	
AS-B09	4.9	CR-22	166	18	Yes	0.75	Fail	Pass	
AS-B11	33.7	SBR-35	124	21	Yes	0.59	Fail	Fail	MS-07
AS-B14	57.8	CR-1	127	23	Yes	0.59	Pass	Fail	MS-06
AS-B15	ND[c]	CR-22	171	10	Yes	0.77	Fail	Pass	
AS-B16	26.7	SBR-35	160	29	Yes	0.76	Fail	Pass	MS-10
AS-B18	32.0	SBR-35	160	15	Yes	0.76	Fail	Pass	

[a] Reference treatments are compared to the control; performance standard is N_{Ref} / $N_{Control} \geq 0.65$.

[b] The appropriate reference failed QA; treatment compared to AS-R1;

[c] No available data; comparison made based on RI/FS (Anchor 2009).

7.4.3 Hart Crowser 2008 RI

Larval tests were conducted on 32 sediments throughout Port Gamble Bay with the mussel, *Mytilus* sp. The controls for both test batches met the SMS acceptability requirement, with 100% and 97% mean normal survivorship (Table 7-9). With the exception of CR-23 MOD in Batch 1, each of the references met the reference sediment performance standard, with >65% mean normal survivorship relative to the control. The medium-grained size reference, CR-23 MOD, failed to meet the reference performance standard with 52.2% normal survivorship relative to the control. For the purposes of the RI, the fine-grained reference CR-20W was used for SMS comparisons.

Table 7-9. Larval Bioassay Results for *Mytilus* sp., Hart Crowser 2008 RI

Station	Percent Fines	Reference	Number Normal		Sig. Diff.	SMS Interpretation N_{Test} / N_{Ref}			Sample Tested in SRI
			Mean	SD		Value	SQS <0.85	CSL <0.70	
Batch 1									
Control	--		304	28			Pass QA (N > 70%)		
MSMP43	6.4	Control[a]	226	32	--	0.74	Pass QA[a]		•
CR20W	79.7	Control[a]	229	19	--	0.75	Pass QA[a]		•
CR23 MOD	51.6	Control[a]	159*	42	--	0.52	Fails QA[a]		•
PGSS-08	87.9	CR20W	205	27	Yes	0.90	Pass	Pass	
PGSS-15	92.7	CR20W	200	29	Yes	0.87	Pass	Pass	
PGSS-16	94.4	CR20W	196	32	Yes	0.86	Pass	Pass	
PGSS-18	94.8	CR20W	177	36	Yes	0.77	Fail	Pass	BW-20
PGSS-20	93.6	CR20W	203	28	Yes	0.89	Pass	Pass	
PGSS-21B	50.2	CR20W	154	32	Yes	0.67	Fail	Fail	BW-17
PGSS-22	92.2	CR20W	140	9	Yes	0.61	Fail	Fail	BW-18
PGSS-29A	69.9	CR20W	177	13	Yes	0.77	Fail	Pass	BW-12
PGSS-30	87.6	CR20W	174	32	Yes	0.76	Fail	Pass	BW-13
PGSS-31	88.6	CR20W	172	40	Yes	0.75	Fail	Pass	BW-14
PGSS-33	87.0	CR20W	185	38	Yes	0.81	Fail	Pass	BW-15
PGSS-35	91.0	CR20W	192	13	Yes	0.84	Fail	Pass	BW-16
PGSS-38A	52.4	CR20W	151	65	Yes	0.66	Fail	Fail	BW-07
PGSS-39	88.7	CR20W	159	46	Yes	0.69	Fail	Fail	BW-08
PGSS-40	84.1	CR20W	157	35	Yes	0.69	Fail	Fail	BW-09
PGSS-42	77.4	CR20W	128	20	Yes	0.56	Fail	Fail	BW-10
Batch 2									
Control	--		277	17					
MSMP43	6.4	Control[a]	203	8	--	0.73		Pass QA[a]	
CR20W	79.7	Control[a]	248	29	--	0.90		Pass QA[a]	
CR23 MOD	51.6	Control[a]	216	30	--	0.78		Pass QA[a]	
PGSS-44	85.4	CR20W	200	28	Yes	0.81	Fail	Pass	BW-11
PGSS-45	85.8	CR20W	215	17	Yes	0.87	Pass	Pass	
PGSS-47	22.0	MSMP43	163	31	Yes	0.80	Fail	Pass	BW-03
PGSS-51	65.3	CR23MOD	209	41	No	0.97	Pass	Pass	BW-04
PGSS-53	58.9	CR23MOD	199	26	No	0.92	Pass	Pass	BW-05
PGSS-54	60.8	CR23MOD	142	30	Yes	0.66	Fail	Fail	BW-06
PGSS-56	12.6	MSMP43	128	23	Yes	0.63	Fail	Fail	BW-02
PGSS-58	70.5	CR20W	216	30	Yes	0.87	Pass	Pass	
PGSS-62	6.7	MSMP43	244	21	No	1.20	Pass	Pass	
PGSS-63	21.8	MSMP43	196	14	No	0.97	Pass	Pass	
PGSS-64	23.2	MSMP43	150	36	Yes	0.74	Fail	Pass	BW-01
PGSS-67	15.3	MSMP43	188	50	No	0.93	Pass	Pass	
PGSS-73	6.1	MSMP43	219	26	No	1.08	Pass	Pass	
PGSS-75	3.9	MSMP43	217	19	No	1.07	Pass	Pass	
PGSS-77A	18.5	MSMP43	214	33	No	1.05	Pass	Pass	
PGSS-92	18.0	MSMP43	198	41	No	0.98	Pass	Pass	

[a] Reference treatments are compared to the control; performance standard is $N_{Ref} / N_{Control} \geq 0.65$.

When compared to the appropriate grain-size reference, 22 of the test treatments had normal survivorship that was significantly different than their associated reference samples (Table 7-9). Sediment from 16 of those stations failed the SQS criterion. Sediment from Stations PGSS-21B, 38A, 39, 40, 42, 54, and 56 also failed the CSL criterion.

Based on a review of the larval toxicity test results, stations with larval test failures were generally associated with fine-grained sediments typical of Port Gamble Bay. The PSEP larval test is susceptible to interference issues in sediments with a high percentage of fine-grained silts and clays (EPA 1993; Ecology 1999; NewFields 2010a,b,c, 2011c; MEC 2004). The PSEP larval test method involves shaking the test sediments in seawater prior to starting the test, with less dense or finer material such as silts, clays, and organic matter separating out and forming a blanket of fine sediment or flocculent material over the sediment surface (Figure 7-1). This stratification is an artifact of the test method and does not represent the sediment as it occurs in nature. In such sediments, the non-swimming, early-stage larvae can become buried or entrained in the finer material that settles after test initiation. When large amounts of fine material are present, larvae can become sufficiently buried that they cannot swim up into the water column once they develop into the motile blastula and gastrula stages. In such cases, the number of larvae recovered is low, but the larvae that are recovered develop normally.

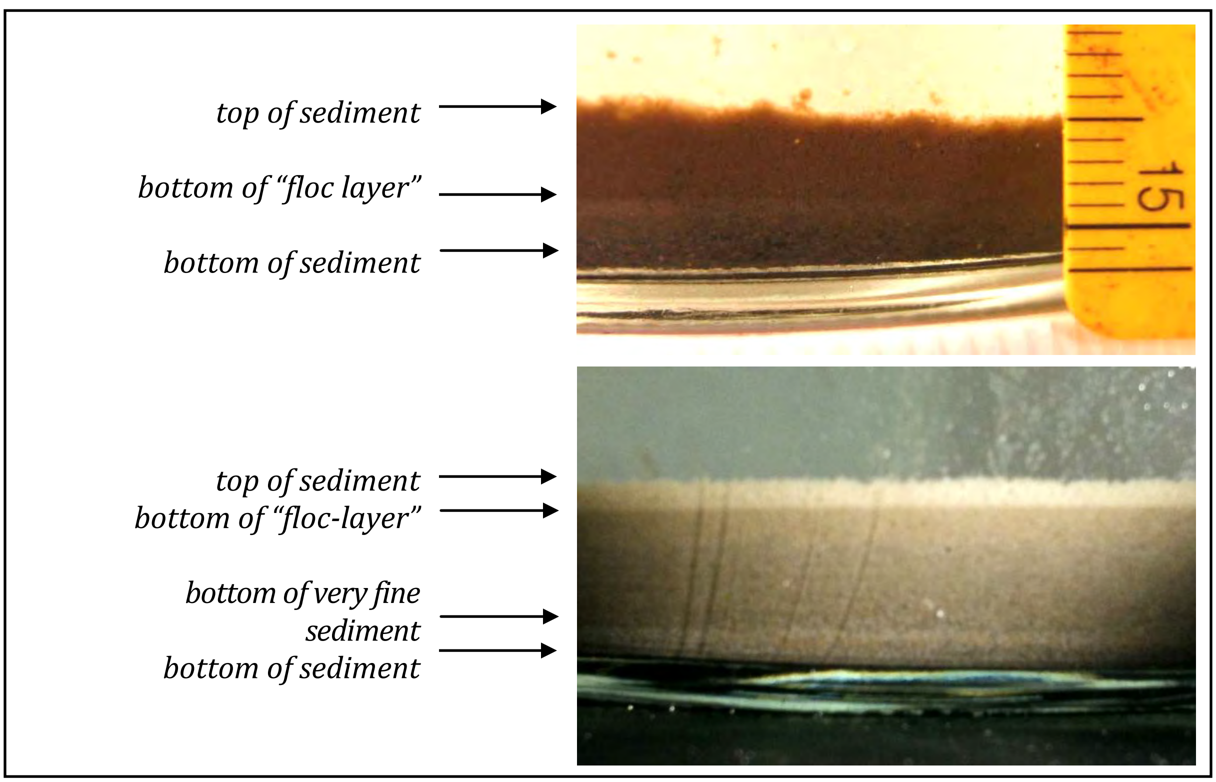

Figure 7-1. Examples of Fine-Grained Sediment and Flocculent Layers Forming in Larval Test Chambers

Recent studies have indicated that buried larvae can still develop normally if sediments are not toxic; however, they are not recovered at the end of the test because they are entrained in the bedded sediment (MEC 2004; NewFields 2010a,b,c). An alternative method for test termination was developed to help understand the potential interference of fine-grained sediment and fine organic matter. In this method, the PSEP test is conducted and terminated following the standard protocol (water overlying the bedded sediment is decanted and then subsampled for larval counts). However, once the subsample is collected, the seawater that has been decanted is poured back into the test chamber with the original sediment and the mixture is homogenized with a perforated plunger. Following a settling period (generally overnight) the test is "re-terminated" following the standard protocol (decanting the overlying water and subsampling for enumeration). Any larvae (normal or abnormal) that were buried, as well as those in the water column, are then recovered and enumerated.

This "resuspension" method has been included in several recent test efforts in Ostrich Bay, Grays Harbor, and the Lower Duwamish River (NewFields 2010a,b; SAIC 2010a,b; SAIC and NewFields 2011). In cases where burial was not an issue, there was little change in the test results. However, for both reference and test sediments in which substantial fine-grained sediments and organic material were present, the number of normal larvae recovered increased, capturing those larvae that were developing within the sediment.

Data from the central and southern portion of Port Gamble Bay indicate that nearly 30% of the sediment is clay, and the formation of a fine-grained layer was observed in the test chambers. The mean number of normal larvae recovered in many of the test treatments in Port Gamble Bay was reduced in the RI; however, a high proportion of the larvae recovered were normally developed. This provided an indication that burial of larval may have affected larval recovery for the fine-grained reference and some of the test treatments evaluated.

7.4.4 NewFields 2011 RI

To better understand the results of the 2009 RI larval tests, a subset of stations were selected for reevaluation using the resuspension method for termination, alongside the standard PSEP method. Selected stations included those that did not pass the SQS or CSL standards, as well as nearby stations that did pass the SMS standards (Table 7-10). The seawater controls met the SMS performance standard, with >90% normal survivorship for test batches 1 and 2 terminated with both the PSEP and resuspension methods. Each of the reference sediments passed the reference performance standard of >65% normal survivorship relative to the control for both test batches. Similar larval recoveries were observed in the reference sediments for both the PSEP and resuspension termination method.

In general, larval recoveries with the PSEP method were similar to those of the previous investigations, with reduced numbers of larvae recovered and >95% normal development (>95% of the larvae recovered developed to normal D-shaped larvae). Using the resuspension method, larval recovery increased for a number of test treatments (BW-04, 05, 05, 07, 08, 09, 10, 11, 13, 14, 15, 20, 21, MS-01, 02, 03, and 04). For these samples, the mean number of normal larvae recovered ranged from 164 to 234 using the PSEP method and from 216 to 301 using the resuspension method. In some cases there was little change in the number of larvae recovered, particularly in the coarser sediment samples (BW-01, 02, 03, 12, 17, MS-5, 08, and 09), as well as some samples with finer-grained sediment (BW-16, 18, 19, MS-06, 07, and 10).

Table 7-10. Larval Bioassay Results for *Mytilus* sp., NewFields 2011 RI

2011 SRI Station	2009 RI Station	Percent Fines	Reference	PSEP Method		Resuspension Method					
				Number Normal		Number Normal		Significant Difference	SMS Interpretation N_{Test} / N_{Ref}		
				Mean	SD	Mean	SD		Value	SQS <0.85	CSL <0.70
Batch 1											
Control	--	--	--	318	15	319	10			Pass QA (N > 70%)	
CI-01	--	6.1	Control[a]	279	45	277	21	--	0.87	Pass QA[a]	
CI-02	--	42.7	Control[a]	273	33	274	35	--	0.86	Pass QA[a]	
CI-03	--	77.7	Control[a]	279	15	262	13	--	0.82	Pass QA[a]	
BW-01	PGSS-64	18.1	CI-01	259	17	269	19	No	0.97	Pass	Pass
BW-02	PGSS-56	8.8	CI-01	291	26	260	14	Yes	0.94	Pass	Pass
BW-03	NA	21.1	CI-01	285	27	250	20	Yes	0.90	Pass	Pass
BW-04	PGSS-51	71.0	CI-03	193	69	270	35	No	1.03	Pass	Pass
BW-05	PGSS-53	64.3	CI-03	199	14	283	11	No	1.08	Pass	Pass
BW-06	PGSS-54	66.2	CI-03	168	24	291	31	No	1.10	Pass	Pass
BW-07	PGSS-38A	53.8	CI-02	217	13	279	12	No	1.03	Pass	Pass
BW-08	PGSS-39	88.2	CI-03	224	28	270	16	No	1.03	Pass	Pass
BW-09	PGSS-40	86.4	CI-03	202	12	265	28	No	1.01	Pass	Pass
BW-10	PGSS-42	81.2	CI-03	175	32	277	24	No	1.06	Pass	Pass
BW-11	PGSS-44	85.7	CI-03	196	42	220	13	Yes	0.84	Fail	Pass
BW-12	NA	48.4	CI-02	207	27	208	20	Yes	0.77	Fail	Pass
BW-13	PGSS-30	87.2	CI-03	179	28	231	17	Yes	0.88	Pass	Pass
BW-14	PGSS-31	90	CI-03	223	17	254	17	No	0.97	Pass	Pass
BW-15	PGSS-33	90.1	CI-03	201	7	222	17	Yes	0.85	Fail	Pass
BW-16	PGSS-35	92.9	CI-03	212	24	202	18	Yes	0.77	Fail	Pass
BW-17	NA	30.8	CI-02	226	26	235	12	Yes	0.87	Pass	Pass

Table 7-10. Larval Bioassay Results for *Mytilus* sp., NewFields 2011 RI

2011 SRI Station	2009 RI Station	Percent Fines	Reference	PSEP Method		Resuspension Method					
				Number Normal		Number Normal		Significant Difference	SMS Interpretation N_{Test} / N_{Ref}		
				Mean	SD	Mean	SD		Value	SQS <0.85	CSL <0.70
Batch 2											
Control	--	--		321	18	297	22			Pass QA (N > 70%)	
CI-01	--	6.1	Control[a]	249	41	295	30	--	0.99	Pass QA[a]	
CI-02	--	42.7	Control[a]	254	23	292	26	--	0.98	Pass QA[a]	
CI-03	--	77.7	Control[a]	279	15	249	22	--	0.79	Pass QA[a]	
BW-18	PGSS-22	86.4	CI-03	168	22	195	7	Yes	0.78	Fail	Pass
BW-19	NA	95.3	CI-03	180	33	210	9	Yes	0.84	Fail	Pass
BW-20	PGSS-18	96.5	CI-03	189	19	224	16	Yes	0.90	Pass	Pass
BW-21	NA	95.3	CI-03	164	15	216	26	Yes	0.87	Pass	Pass
MS-01	AS-01	27.4	CI-02	234	22	299	32	No	1.01	Pass	Pass
MS-02	AS-104	18.0	CI-01	235	26	301	21	No	1.02	Pass	Pass
MS-03	AS-03	25.5	CI-02	228	33	264	16	Yes	0.93	Pass	Pass
MS-04	AS-05	55.8	CI-02	214	17	280	25	Yes	0.97	Pass	Pass
MS-05	NA	17.1	CI-02	242	17	249	20	No	0.87	Pass	Pass
MS-06	AS-B14	50.8	CI-01	209	15	230	13	Yes	0.81	Fail	Pass
MS-07	AS-B11	32.7	CI-02	200	52	224	68	Yes	0.79	Fail	Pass
MS-08	AS-14	7.1	CI-02	245	11	238	14	No	0.83	Fail	Pass
MS-09	NA	16.3	CI-01	205	27	213	34	Yes	0.74	Fail	Pass
MS-10	AS-B16	38..5	CI-02	217	19	240	16	Yes	0.84	Fail	Pass

[a] Reference treatments are compared to the control; performance standard is N_{Ref} / $N_{Control}$ ≥ 0.65.

For the purposes of evaluating sediment quality under SMS, the results of the resuspension method were used. When compared to the appropriate grain-size reference, 12 of the test treatments had normal survivorship that was significantly different than their associated reference samples (Table 7-10). Sediment from 12 stations (BW-11, 12, 15, 16, 18, 19, MS-06, 07, 08, 09, and 10) failed the SQS criterion, with <85% normal survivorship relative to reference. All of the test sediments passed the CSL criterion for the larval test.

7.5 SMS Interpretation

SMS determinations of toxicity were based on data collected in the Mill Area and Port Gamble Bay RI and SRI investigations, with test results from the 2011 Supplemental RI superseding those of the previous studies in cases where stations were retested. The SQS for toxicity is exceeded if one of the sediment biological tests failed the specified SQS criterion. The CSL is exceeded if one test failed its CSL criterion or if two tests failed their SQS criteria. A total of 21 locations in Port Gamble Bay exceeded the SQS, based on the larval test (Table 7-11 and Figure 7-2). None of these stations exceeded the CSL for the larval test. Two of the 61 locations evaluated in Port Gamble Bay (Stations MS-01 and MS-03) exceeded the CSL due to a CSL exceedance for the amphipod test.

Table 7-11. SMS Interpretation of Toxicity Test Results

Station	Amphipod Mortality	Juvenile Polychaete Growth	Larval Development	SMS Interpretation
AS-02	Pass	Pass	Fails SQS	Fails SQS
AS-07	Pass	Pass	Fails SQS	Fails SQS
AS-09	Pass	Pass	Fails SQS	Fails SQS
AS-101	Pass	--	Pass	Pass
AS-102	Pass	--	Pass	Pass
AS-106	Pass	--	Fails SQS	Fails SQS
AS-108	Pass	--	Pass	Pass
AS-112	Pass	--	Fails SQS	Fails SQS
AS-113	Pass	--	Fails SQS	Fails SQS
AS-13	Pass	Pass	Fails SQS	Fails SQS
AS-3002	Pass	Pass	Pass	Pass
AS-B09	Pass	--	Fails SQS	Fails SQS
AS-B15	Pass	--	Fails SQS	Fails SQS
AS-B18	Pass	Pass	Fails SQS	Fails SQS
BW-01	Pass[a]	Pass[a]	Pass	Pass
BW-02	Pass[a]	Pass[a]	Pass	Pass
BW-03	Pass[a]	Pass[a]	Pass	Pass
BW-04	Pass[a]	Pass[a]	Pass	Pass
BW-05	Pass[a]	Pass[a]	Pass	Pass
BW-06	Pass[a]	Pass[a]	Pass	Pass
BW-07	Pass[a]	Pass[a]	Pass	Pass
BW-08	Pass[a]	Pass	Pass	Pass
BW-09	Pass[a]	Pass	Pass	Pass
BW-10	Pass[a]	Pass[a]	Pass	Pass
BW-11	Pass[a]	Pass[a]	Fails SQS	Fails SQS
BW-12	Pass[b]	Pass	Fails SQS	Fails SQS

BW-13	Pass[a]	Pass	Pass	Pass

Table 7-11. SMS Interpretation of Toxicity Test Results

Station	Amphipod Mortality	Juvenile Polychaete Growth	Larval Development	SMS Interpretation
BW-14	Pass[a]	Pass	Pass	Pass
BW-15	Pass[a]	Pass	Fails SQS	Fails SQS
BW-16	Pass[a]	Pass[a]	Fails SQS	Fails SQS
BW-17	Pass[a]	Pass	Pass	Pass
BW-18	Pass[a]	Pass[a]	Fails SQS	Fails SQS
BW-19	--	Pass	Fails SQS	Fails SQS
BW-20	Pass[a]	Pass	Pass	Pass
BW-21	--	Pass	Pass	Pass
MS-01	Fails CSL[b]	Pass	Pass	Fails CSL
MS-02	Pass[c]	Pass	Pass	Pass
MS-03	Fails CSL[b]	Pass	Pass	Fails CSL
MS-04	Pass[b]	Pass	Pass	Pass
MS-05	--	Pass	Pass	Pass
MS-06	Pass[c]	--	Fails SQS	Fails SQS
MS-07	Pass[c]	--	Fails SQS	Fails SQS
MS-08	Pass[b]	Pass	Fails SQS	Fails SQS
MS-09	--	Pass	Fails SQS	Fails SQS
MS-10	Pass[c]	Pass	Fails SQS	Fails SQS
PGSS-8	Pass	Pass	Pass	Pass
PGSS-15	Pass	Pass	Pass	Pass
PGSS-16	Pass	Pass	Pass	Pass
PGSS-20	Pass	Pass	Pass	Pass
PGSS-45	Pass	Pass	Pass	Pass
PGSS-46	Pass	Pass	Pass	Pass
PGSS-58	Pass	Pass	Pass	Pass
PGSS-62	Pass	Pass	Pass	Pass
PGSS-62B	Pass	Pass	Pass	Pass
PGSS-63	Pass	Pass	Pass	Pass
PGSS-67	Pass	Pass	Pass	Pass
PGSS-69	Pass	Pass	Pass	Pass
PGSS-73	Pass	Pass	Pass	Pass
PGSS-75	Pass	Pass	Pass	Pass
PGSS-77A	Pass	Pass	Pass	Pass
PGSS-92	Pass	Pass	Pass	Pass

[a]Determination based on data collected during the Hart Crowser 2008 RI (Hart Crowser 2010).

[b]Determination based on data collected during the Anchor 2006 Mill Area RI (Anchor 2006a).

[c]Determination based on data collected during the Anchor 2008 Mill Area SRI (Anchor 2009).

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8.0 HUMAN HEALTH RISK

Human health risk is one important component of developing cleanup standards for the site and identifying site boundaries and SMAs. The cleanup standard is defined as the highest of 1) risk-based concentrations, 2) natural background concentrations, and 3) practical quantitation limits (PQLs). This section addresses human health risk, Section 9 addresses natural background comparisons, and Section 11 describes how these are combined with PQLs to identify contaminants of concern and select site-specific cleanup levels.

This assessment focuses on risks associated with tribal collection and ingestion of shellfish from Port Gamble Bay. Risks are presented for concentrations found in shellfish and intertidal sediments Port Gamble Bay, as well as natural background concentrations for Puget Sound.

8.1 Exposure Pathways and Reasonable Maximum Exposure Scenarios

Two exposure pathways were identified for Port Gamble Bay:

- Ingestion of shellfish, using tribal consumption rates that are considered protective of other subsistence and recreational consumers.
- Direct sediment contact (incidental sediment ingestion and dermal contact) during shellfish gathering.

Four reasonable maximum exposure (RME) scenarios were developed to address these exposure pathways: (1) adult and child tribal seafood ingestion scenarios, with a focus on shellfish ingestion, and (2) adult and child tribal clamming scenario. The RME scenarios were developed for Port Gamble Bay based on the EPA tribal framework document (EPA 2007). As described below, procedures and relevant exposure parameter values were taken from the recent EPA and Ecology-approved human health risk assessment for the LDW site, including direction from EPA regarding exposure parameters for shellfish ingestion and the clamming RME scenarios (Windward 2007).

In addition to shellfish collection and ingestion, risk from incidental contact with potentially contaminated sediment could occur from activities such as recreational use of the intertidal areas of the bay or use of fishing nets. However, these risks are expected to be significantly lower than the exposure pathways evaluated below.

8.2 Ingestion of Shellfish

For tribal ingestion of shellfish, CoPCs, exposure data for shellfish, and calculation of exposures as chronic daily intake (CDI) are presented below.

8.2.1 Chemicals of Potential Concern

CoPCs were identified in the screening level risk assessment (Hart Crowser 2009). In addition, mercury was added due to its potential to accumulate in seafood. The following CoPCs were evaluated:

- Metals, including arsenic, cadmium, copper, and mercury
- cPAHs
- PCBs, both as Aroclors and selected PCB congeners with dioxin-like activity
- PCDD/PCDFs, congeners, and homolog groups

8.2.2 Target Species

Shellfish species evaluated included Dungeness crab, geoduck, oysters, littleneck clams, manila clams, and cockles. Numbers and locations of tissue samples as well as tissue concentrations of the above CoPCs are presented in Sections 3.3 and 6.0 and in Appendix A.

8.2.3 Site-Specific Consumption Rates

Consumption rates for each of these seafood categories were developed following the EPA Tribal Fish and Shellfish Consumption Framework (EPA 2007) and consultation with the Port Gamble S'Klallam Tribe. In addition, although salmon are a highly preferred and consumed fish from Port Gamble Bay, human health risks were not calculated for salmon consumption. Port Gamble Bay sediment contaminants are not expected to significantly contribute to salmon tissue concentrations because of the relatively small portion of their lifetime spent in the bay, consistent with the EPA Framework document (EPA 2007).

A daily tribal shellfish consumption rate of 499 g/day was used, with the following breakdown for the species collected from the bay:

- Geoduck – 96.8 g/day. Samples submitted for analysis included the gutball; the skin was removed from the siphon prior to analysis.
- Clams – 255.9 g/day, whole organism without shell. Littleneck clams, manila clams, and cockles were pooled together under the clam category.
- Oysters – 62.4 g/day, whole organism without shell.
- Dungeness crab – 83.9 g/day, assuming 25% hepatopancreas (20.975 g/day) and 75% meat (62.925 g/day), which were analyzed separately.

The total ingestion rate for shellfish was consistent with the Tribal Framework Document (EPA 2007) using the Suquamish survey data, as agreed between Ecology and the Port Gamble S'Klallam Tribe. The total shellfish ingestion rate was allocated among the shellfish categories of clams, geoducks, oysters, and crabs following the rates identified by EPA in the risk assessment for the LDW site (Windward 2007).

8.2.4 Chemical-Specific Summation Methods

Dioxins/furans, PCBs, and PAHs were evaluated as chemical groups. The PCB, dioxin/furan, and cPAH TEQs were calculated by applying the TEF to each congener or chemical and then summing multiple chemical values using KM summation methods where appropriate (Helsel 2010) or substitution at one-half the detection limit. The KM sum was only calculated when the frequency of detection was 50% or greater across all congeners or individual chemicals within a sample, otherwise simple substitution at one-half the detection limit was used for all congeners. When TEQs were calculated using the KM method, if the highest or lowest toxic equivalency concentrations (TECs) were non-detects these were treated as detected as reported to avoid a low bias in the KM estimation method.

The following chemical-specific methods were used:

- Dioxins/furans were represented as total TCDD toxic equivalents (TEQs). WHO 2005 dioxin TEFs from MTCA Table 708-1 were used to calculate total TEQs.
- PCBs were represented both as the sum of Aroclors and TCDD TEQs for PCB congeners with dioxin-like activity. Aroclors were summed following the procedure described in the SMS. WHO 2005 PCB congener TEFs listed in MTCA Table 708-4 were used to calculate PCB TEQs.
- cPAHs were represented as benzo(a)pyrene TEQs. The California-EPA 2005 cPAH TEFs listed in MTCA Table 708-2 were used to calculate benzo(a)pyrene equivalents.
- The toxic and carcinogenic form of arsenic is inorganic arsenic. The amount of inorganic arsenic in the shellfish categories was estimated from the measured total arsenic by assuming 1.2% inorganic arsenic in clams, and 0.2% inorganic arsenic in crabs, as documented for Puget Sound organisms (Ecology 2002).

8.2.5 Exposure Point Concentrations

The exposure point concentration (EPC) was calculated as:

- The smaller of the maximum detected concentration or the 95th upper confidence limit (UCL) on the mean for CoPCs with at least one detected concentration.
- The maximum non-detect value was used as a proxy for the EPC for the CoPCs with no detected concentrations.

All EPC calculations and distributional evaluations were performed in ProUCL version 4.1.

The distribution for each CoPC data set was evaluated to determine if it followed a normal, lognormal, or gamma distribution at the 0.05 significance level, using appropriate methods for censored data when non-detected values were present. If a parametric distribution was found to be suitable by the goodness of fit tests used by ProUCL 4.1, then suitable parametric estimates of the 95th UCL on the mean were calculated. Otherwise, non-parametric estimates of the 95th UCL on the mean were calculated using the method most suited to the data, per ProUCL recommendations. A minimum of five samples was necessary to determine the distribution and calculate a UCL.

The specific methods used for each CoPC are identified in the EPC tables in Appendix B.

8.2.6 Risk Calculations

Carcinogenic risks and noncarcinogenic health effects were evaluated separately because of differences in assumptions about the mechanism of these toxic effects. The toxicity values used to evaluate exposure to chemicals with noncarcinogenic and carcinogenic effects are the reference dose (RfD) and cancer slope factor (CSF), respectively.

Carcinogenic chemicals are assumed to have no threshold for carcinogenicity. Carcinogenic risks are presented as the chance of contracting cancer over a 70-year lifetime due to site-related exposure. These risks are considered excess cancer risks that are in addition to the national rates of cancer for the general population (approximately a 1 in 3 chance, according to the American Cancer Society). For example, a 1×10^{-6} risk predicts that one person in a population of one million will develop cancer due to site-related exposures.

Noncarcinogenic risks are considered to have a threshold concentration (reference dose or RfD) above which some form of toxic response may be experienced. These types of risk are evaluated using a hazard quotient (HQ), which is the ratio of the exposure concentration to the lowest concentration that has toxic effects. For example, a hazard quotient of 2 indicates that a person has been exposed to twice the lowest concentration thought to have adverse effects. This concentration may or may not result in the more toxic effects possible for that chemical; higher hazard quotients indicate greater risks and a greater possibility of more severe effects.

Contaminant data for evaluating exposures from shellfish consumption were available for crabs, clams, oysters, and geoducks collected from Port Gamble Bay and for natural background areas in Puget Sound. CDIs were calculated for the CoPCs identified above. The CDI for the adult tribal ingestion scenario for each tissue was calculated as follows:

$$CDI_a = \frac{EPC \cdot IR \cdot FI \cdot EF \cdot ED}{BW \cdot AT}$$

where

CDI_a = Chronic daily intake for adult ingestion (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
IR = Ingestion rate (kg/day)
FI = Fractional exposure (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

The CDI for the child tribal ingestion scenario for each tissue was calculated as follows:

$$CDI_c = \sum_{i=1}^{6} \frac{EPC \cdot IR \cdot FI \cdot EF \cdot ED_i}{BW_i \cdot AT}$$

where

CDI_c = Chronic daily intake for child ingestion (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
IR = Ingestion rate (kg/day)
FI = Fractional exposure (unitless)
EF = Exposure frequency (days/year)
ED_i = Exposure duration (years) for years i = 1, 2, 3, 4, 5, 6
BW_i = Body weight (kg) for years i = 1, 2, 3, 4, 5, 6
AT = Averaging time (days)

Table 8-1 shows the exposure parameters that were assumed for these calculations for ingestion of crabs, clams, whole body geoduck, and oysters.

After the CDI was calculated for ingestion for each carcinogenic CoPC and tissue, ingestion risks for adult and child were calculated as follows:

$$risk_a = CDI_a \cdot SFo$$

$$risk_c = CDI_c \cdot SFo$$

where

CDI_c = Chronic daily intake for child ingestion (mg/kg-day)
CDI_a = Chronic daily intake for adult ingestion (mg/kg-day)
$risk_a$ = Ingestion risk for adult (unitless)
$risk_c$ = Ingestion risk for child (unitless)
SFo = Carcinogenic slope factor for oral ingestion (kg-day/mg)

Ingestion HQs for adult and child were calculated as follows:

$$HQ_a = \frac{CDI_a}{RfDo}$$

$$HQ_c = \frac{CDI_c}{RfDo}$$

where

CDI_a = Chronic daily intake for adult ingestion (mg/kg-day)
CDI_c = Chronic daily intake for child ingestion (mg/kg-day)
HQ_a = Non-carcinogenic hazard adult quotient (unitless)
HQ_c = Non-carcinogenic hazard child quotient (unitless)
RfDo = Non-carcinogenic reference dose for oral ingestion (mg/kg-day)

The carcinogenic SFo and non-carcinogenic RfD toxicity values were obtained from the June 2011 EPA Regional Screening Levels (RSLs) at http://www.epa.gov/region9/superfund/prg/, except that in accordance with MTCA, a CPF of $1.5x10^5$ was used for dioxins/furans and dioxin-like PCBs. Table 8-2 shows the carcinogenic toxicity values used in the human health risk assessment calculations for all CoPCs for both sediment and tissue. Table 8-3 shows the non-carcinogenic toxicity values used in the human health risk assessment calculations for all CoPCs for both sediment and tissue.

Table 8-1. Exposure Parameters for Tissue Ingestion

Parameter	Units	Clams		Crab - hepatopancreas		Crabs - muscle		Geoduck		Oysters	
		Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child
Ingestion											
Tissue ingestion rate	kg/day	0.2559[a]	0.0151[b]	0.020975[a]	0.0042[b]	0.062925[a]	0.0132[b]	0.062925[a]	0.0151[b]	0.062925[a]	0.0151[b]
Fraction of exposure[a]	unitless	1	1	1	1	1	1	1	1	1	1
Exposure frequency[a]	days/year	365	365	365	365	365	365	365	365	365	365
Exposure duration[a]	years	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1
Body weight[a]	kg	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7
Carcinogen averaging time	days	25,550	25,550	25,550	25,550	25,550	25,550	25,550	25,550	25,550	25,550
Noncarcinogen averaging time	days	25,550	2190	25,550	2190	25,550	2190	25,550	2190	25,550	2190

[a] Hart Crowser (2009)

[b] Windward (2007)

Table 8-2. Carcinogenic Toxicity Values for Ingestion and Dermal Pathways

Analysis Type	CoPC	CAS Number	Oral SF (kg-day/mg)	GAF (unitless)	AF (mg/cm^2-day)	ABS (unitless)	Dermal SF (kg-day/mg)
Inorganics	Arsenic (inorganic)	7440-38-2	1.5	1	0.2	0.03	1.5
Inorganics	Cadmium (diet)	7440-43-9	--	0.025	0.2	0.001	--
Inorganics	Copper	7440-50-8	--	1	0.2	--	--
Inorganics	Mercury (as mercuric chloride)	7439-97-6	--	0.07	0.2	--	--
PAH	cPAH TEQ (BaP)	50-32-8	7.3	1	0.2	0.13	7.3
PCB	PCB TEQ (2,3,7,8-TCDD)	1746-01-6	1.5E+05	1	0.2	0.03	1.5E+05
Dioxin/Furan	Dioxin/Furan TEQ (2,3,7,8-TCDD)	1746-01-6	1.5E+05	1	0.2	0.03	1.5E+05

SF = slope factor

GAF = gastrointestinal absorption factor

AF = adherence factor

ABS = dermal absorption fraction

Table 8-3. Non-carcinogenic Toxicity Values for Ingestion and Dermal Pathways

Analysis Type	CoPC	CAS Number	Oral RfD (mg/kg-day)	GAF (unitless)	AF (mg/cm^2-day)	ABS (unitless)	Dermal RfD (mg/kg-day)
Inorganics	Arsenic (inorganic)	7440-38-2	3.0E-04	1	0.2	0.03	3.0E-04
Inorganics	Cadmium (diet)	7440-43-9	0.001	0.025	0.2	0.001	2.5E-05
Inorganics	Copper	7440-50-8	0.04	1	0.2	--	0.04
Inorganics	Mercury (as mercuric chloride)	7439-97-6	0.0003	0.07	0.2	--	2.1E-05
PAH	cPAH TEQ (BaP)	50-32-8	--	1	0.2	0.13	--
PCB	PCB TEQ (2,3,7,8-TCDD)	1746-01-6	1.0E-09	1	0.2	0.03	1.0E-09
Dioxin/Furan	Dioxin/Furan TEQ (2,3,7,8-TCDD)	1746-01-6	1.0E-09	1	0.2	0.03	1.0E-09

RfD = reference dose

GAF = gastrointestinal absorption factor

AF = adherence factor

ABS = dermal absorption fraction

8.3 Dermal and Ingestion Exposure to Beach Sediments

EPCs for dermal exposure and incidental ingestion of intertidal sediments during clam-digging or other beach use were calculated as described for the ingestion pathway using intertidal sediment data for Port Gamble Bay, and are shown in tables in Appendix B.

8.3.1 Ingestion of Intertidal Sediments

The CDI for the adult tribal ingestion scenario for sediment was calculated as follows:

$$CDI_{ing,a} = \frac{EPC \cdot IR \cdot FI \cdot EF \cdot ED}{BW \cdot AT}$$

where

$CDI_{ing,a}$ = Chronic daily intake for ingestion for adult (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
IR = Ingestion rate (kg/day)
FI = Fractional exposure (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

The CDI for the child tribal ingestion scenario for sediment was calculated as follows:

$$CDI_{ing,c} = \sum_{i=1}^{6} \frac{EPC \cdot IR \cdot FI \cdot EF \cdot ED_i}{BW_i \cdot AT}$$

where

$CDI_{ing,c}$ = Chronic daily intake for ingestion for child (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
IR = Ingestion rate (kg/day)
FI = Fractional exposure (unitless)
EF = Exposure frequency (days/year)
ED_i = Exposure duration (years) for years *i* = 1, 2, 3, 4, 5, 6
BW_i = Body weight (kg) for years *i* = 1, 2, 3, 4, 5, 6
AT = Averaging time (days)

Table 8-4 shows the exposure parameters that were assumed for the ingestion calculations.

After the CDI was calculated for ingestion for each CoPC, ingestion risks for adult and child were calculated as follows:

$$risk_{ing,a} = CDI_{ing,a} \cdot SFo$$

$$risk_{ing,c} = CDI_{ing,c} \cdot SFo$$

where

$CDI_{ing,c}$ = Chronic daily intake for ingestion for child (mg/kg-day)
$CDI_{ing,a}$ = Chronic daily intake for ingestion for adult (mg/kg-day)
$risk_{ing,a}$ = Ingestion risk for adult (unitless)
$risk_{ing,c}$ = Ingestion risk for child (unitless)
SFo = Carcinogenic slope factor for oral ingestion (kg-day/mg)

Ingestion HQs for adult and child were calculated as follows:

$$HQ_{ing,a} = \frac{CDI_{ing,a}}{RfDo}$$

$$HQ_{ing,c} = \frac{CDI_{ing,c}}{RfDo}$$

where

$CDI_{ing,c}$	=	Chronic daily intake for ingestion for child (mg/kg-day)
$CDI_{ing,a}$	=	Chronic daily intake for ingestion for adult (mg/kg-day)
$HQ_{ing,a}$	=	Non-carcinogenic hazard quotient for adult (unitless)
$HQ_{ing,c}$	=	Non-carcinogenic hazard quotient for child (unitless)
RfDo	=	Non-carcinogenic reference dose for oral ingestion (mg/kg-day)

The carcinogenic SFo and non-carcinogenic RfDo toxicity values are listed in Tables 8-2 and 8-3.

Table 8-4. Exposure Parameters for Intertidal Sediment Ingestion

Parameter	Units	Adult Tribal	Child Tribal
Sediment ingestion rate	kg/day	0.0001[a]	0.0002[b]
Fraction of exposure[b]	unitless	1	1
Exposure frequency[b]	days/year	365	365
Exposure duration	years	70[b]	(<1 yr) 1[c] (1–2) 1[c] (2–3) 1[c] (3–4) 1[c] (4–5) 1[c] (5–6) 1[c]
Body weight	kg	79[b]	(<1 yr) 9.1[c] (1–2) 11.3[c] (2–3) 13.3[c] (3–4) 15.3[c] (4–5) 17.4[c] (5–6) 19.7[c]
Carcinogen averaging time	days	25,550	25,550
Noncarcinogen averaging time	days	25,550	2190

[a] U.S. EPA default

[b] Hart Crowser (2009)

[c] Windward (2007)

8.3.2 Dermal Exposure to Intertidal Sediments

The CDI for the adult tribal dermal scenario for sediment was calculated as follows:

$$CDI_{der,a} = \frac{EPC \cdot CF \cdot SA \cdot AF \cdot ABS \cdot EF \cdot ED}{BW \cdot AT}$$

where

$CDI_{der,a}$ = Chronic daily intake for dermal for adult (mg/kg-day)

EPC = Exposure point concentration (mg/kg)

CF = Conversion factor (kg/mg)

SA = Skin area (cm^2)

AF = Adherence factor (mg/cm^2-day)

ABS = Absorption fraction (unitless)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (kg)

AT = Averaging time (days)

The CDI for the child tribal dermal scenario for sediment was calculated as follows:

$$CDI_{der,c} = \sum_{i=1}^{6} \frac{EPC \cdot CF \cdot SA_i \cdot AF \cdot ABS \cdot EF \cdot ED_i}{BW_i \cdot AT}$$

where

$CDI_{der,c}$ = Chronic daily intake for dermal for child (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
CF = Conversion factor (kg/mg)
SA_i = Skin area (cm^2) for years *i* = 1, 2, 3, 4, 5, 6
AF = Adherence factor (mg/cm^2-day)
ABS = Absorption fraction (unitless)
EF = Exposure frequency (days/year)
ED_i = Exposure duration (years) for years *i* = 1, 2, 3, 4, 5, 6
BW_i = Body weight (kg) for years *i* = 1, 2, 3, 4, 5, 6
AT = Averaging time (days)

Table 8-5 shows the exposure parameters that were assumed for sediment calculations for dermal exposure.

After the CDI was calculated for dermal exposure for each CoPC, adult and child dermal risks were calculated as follows:

$$risk_{der,a} = CDI_{der,a} \cdot SFd$$

$$risk_{der,c} = CDI_{der,c} \cdot SFd$$

where

$CDI_{der,c}$ = Chronic daily intake for dermal for child (mg/kg-day)
$CDI_{der,a}$ = Chronic daily intake for dermal for adult (mg/kg-day)
$risk_{der,a}$ = Carcinogenic dermal risk for adult (unitless)
$risk_{der,c}$ = Carcinogenic dermal risk for child (unitless)
SFd = Carcinogenic slope factor for dermal (kg-day/mg)

Dermal HQs for adult and child were calculated as follows:

$$HQ_{der,a} = \frac{CDI_{der,a}}{RfDd}$$

$$HQ_{der,c} = \frac{CDI_{der,c}}{RfDd}$$

where

$CDI_{der,c}$ = Chronic daily intake for dermal for child (mg/kg-day)
$CDI_{der,a}$ = Chronic daily intake for dermal for adult (mg/kg-day)
$HQ_{der,a}$ = Non-carcinogenic dermal hazard quotient for adult (unitless)
$HQ_{der,c}$ = Non-carcinogenic dermal hazard quotient for child (unitless)
RfDd = Non-carcinogenic reference dose for dermal (mg/kg-day)

The carcinogenic SFd dermal toxicity values were derived from the oral slope factors using the gastrointestinal absorption factors listed in Table 8-2. Similarly, the non-carcinogenic RfDd dermal toxicity values were derived from the oral reference doses listed in Table 8-3.

Table 8-5. Exposure Parameters for Sediment Dermal Exposure

Parameter	Units	Adult Tribal	Child Tribal
Skin area	cm^2	5700[a]	(<1 yr) 1330[b] (1–2) 1750[b] (2–3) 2069[b] (3–4) 2298[b] (4–5) 2515[b] (5–6) 2751[b]
Adherence factor	mg/cm^2-day	0.07[a]	0.2
Absorption fraction	unitless	CS	CS
Exposure frequency	days/year	365	365
Exposure duration	years	70[c]	(<1 yr) 1[b] (1–2) 1[b] (2–3) 1[b] (3–4) 1[b] (4–5) 1[b] (5–6) 1[b]
Body weight	kg	79[c]	(<1 yr) 9.1[b] (1–2) 11.3[b] (2–3) 13.3[b] (3–4) 15.3[b] (4–5) 17.4[b] (5–6) 19.7[b]
Carcinogen averaging time	days	25,550	25,550
Noncarcinogen averaging time	days	25,550	2190
Conversion factor	kg/mg	1E-6	1E-6

CS = contaminant-specific value
[a] U.S. EPA default
[b] Windward (2007)
[c] Hart Crowser (2009)

8.4 Risk Characterization

8.4.1 Port Gamble Bay

Table 8-6 and Figure 8-1 summarize the risks for all exposure pathways and tissue types for Port Gamble Bay, for the tribal shellfish consumption and beach exposure scenarios described above. Detailed calculations for the risk assessment are presented in Appendix B.

Total carcinogenic risks to adults are 9.0×10^{-4} for the seafood ingestion pathway, exceeding the MTCA/SMS risk threshold of 1×10^{-5}. Carcinogenic risks to children are 6.7×10^{-5}. The total hazard index for noncarcinogenic chemicals is 7.9 for adults and 7.4 for children, both greater than the 1.0 MTCA/SMS risk threshold. In general, risks to children are lower than those to adults.

Dermal and ingestion exposures to intertidal sediments are in the $7–8 \times 10^{-6}$ range for adults and children, below the cumulative MTCA/SMS threshold. Arsenic contributes the majority of this risk. The hazard index is ≤0.23, below the MTCA/SMS threshold.

Inorganic arsenic, dioxin/furans, PCB dioxin-like congeners, and cPAHs for all tissues and pathways combined have cancer risks above the 1×10^{-6} threshold for individual chemicals, for both the adult and child scenarios:

- Inorganic arsenic, adult cancer risk = 2.5×10^{-4}, child cancer risk = 1.9×10^{-5}
- cPAH TEQ, adult cancer risk = 1.9×10^{-4}, child cancer risk = 1.6×10^{-5}
- PCB congener TEQ, adult cancer risk = 1.2×10^{-4}, child cancer risk = 1.0×10^{-5}
- Dioxin/furan TEQ, adult cancer risk = 3.6×10^{-4}, child cancer risk = 2.9×10^{-5}

From the above, it can be seen that each of these chemicals or chemical classes contributes roughly equally to the overall risk from ingestion of shellfish. The risk from exposure to intertidal sediments is significantly lower, and is primarily associated with inorganic arsenic.

Among the individual chemicals and groups, cadmium, copper, and the dioxin/furan TEQ had hazard quotients >1.0:

- Cadmium, adult HQ = 2.8, child HQ = 2.6
- Copper, adult HQ = 1.2, child HQ = 1.1
- Dioxins/furans, adult HQ = 2.4, child HQ = 2.3

HQs for arsenic, mercury, and PCBs were <1.0.

8.4.2 Natural Background

Table 8-7 and Figure 8-2 summarize the risks for natural background concentrations of the human health CoPCs in tissues in Puget Sound (see Section 9.2 for a description of the natural background data set). Natural background risks could not be calculated for oysters or for intertidal sediment exposures due to lack of data. Detailed calculations for the risk assessment are presented in Appendix B.

Total carcinogenic risks to adults associated with natural background concentrations in Puget Sound are $2.5x10^{-3}$ for the tribal seafood ingestion exposure scenario, also above the cumulative MTCA/SMS risk threshold of $1x10^{-5}$. Carcinogenic risks to children are $1.1x10^{-4}$. The total hazard index for noncarcinogenic chemicals is 9.1 for adults and 6.5 for children, both greater than the 1.0 MTCA/SMS risk threshold. In general, risks to children are lower than those to adults.

Inorganic arsenic, dioxin/furans, and cPAHs have cancer risks above the $1x10^{-6}$ threshold for individual chemicals, for both the adult and child scenarios:

- Inorganic arsenic, adult cancer risk = $2.1x10^{-3}$, child cancer risk = $7.3x10^{-5}$
- cPAH TEQ, adult cancer risk = $4.1x10^{-5}$, child cancer risk = $2.0x10^{-6}$
- Dioxin/furan TEQ, adult cancer risk = $3.7x10^{-4}$, child cancer risk = $3.1x10^{-5}$

Among the individual chemicals and groups, arsenic, cadmium and the dioxin/furan TEQ have hazard quotients >1.0:

- Arsenic, adult HQ = 4.6, child HQ = 1.9
- Cadmium, adult HQ = 1.2, child HQ = 1.1
- Dioxins/furans, adult HQ = 2.4, child HQ = 2.4

Hazard quotients for copper and mercury were <1.0.

Table 8-8 and Figures 8-3 and 8-4 provide a summary comparison of risks associated with shellfish ingestion from Port Gamble Bay vs. natural background concentrations in Puget Sound. Based on Table 8-8 and the above comparisons, some general conclusions can be drawn:

- Overall risks from consumption of Port Gamble Bay shellfish are similar to or slightly lower than risks associated with shellfish from natural background areas in Puget Sound. This is true even though PCBs are included in the Port Gamble data, but there were no PCB congener data available for natural background areas. These differences are relatively small and likely within the error of the calculations.
- Risks for clams contribute most to the total risk in both areas, but particularly in natural background areas of Puget Sound.
- Detailed comparison of Tables 8-6 and 8-7 reveals some chemical-specific differences in risk between natural background areas and Port Gamble Bay. In general, risks associated with arsenic in the greater Puget Sound region are higher than in Port Gamble Bay, while risks associated with cadmium, copper, and cPAHs are higher in Port Gamble Bay than in Puget Sound. Risks associated with dioxins/furans are very similar between the two areas.

Table 8-6. Human Health Risks from Exposure to Tissues and Sediments of Port Gamble Bay

		All Chemicals		Arsenic*		Cadmium	Copper	Mercury	cPAH TEQ	PCB TEQ		Dioxin/Furan TEQ	
Medium	**Receptor**	**Risk**	**HI**	**Risk**	**HQ**	**HQ**	**HQ**	**HQ**	**Risk**	**Risk**	**HQ**	**Risk**	**HQ**
Clams	Adult	**4.1E-04**	**3.12**	1.6E-04	0.32	1.2	0.4	0.09	8.3E-05	2.7E-05	0.18	1.4E-04	0.93
Clams	Child	**1.2E-05**	**1.09**	4.3E-06	0.11	0.42	0.14	0.031	2.5E-06	8.1E-07	0.063	4.2E-06	0.33
Crab hepatopancreas	Adult	**1.7E-04**	**1.57**	6.4E-06	0.014	0.37	0.13	0.027	6.6E-06	6.6E-05	0.44	8.8E-05	0.59
Crab hepatopancreas	Child	**1.7E-05**	**1.86**	6.4E-07	0.017	0.44	0.15	0.031	6.6E-07	6.6E-06	0.52	8.9E-06	0.7
Crab muscle	Adult	**9.0E-05**	**0.72**	1.7E-05	0.037	0.032	0.17	0.13	2.1E-05	7.5E-06	0.05	4.4E-05	0.3
Crab muscle	Child	**9.5E-06**	**0.87**	1.8E-06	0.05	0.04	0.21	0.15	2.2E-06	8.0E-07	0.062	4.7E-06	0.36
Geoduck whole body	Adult	**1.0E-04**	**0.64**	2.9E-05	0.064	0.15	0.065	0.027	2.1E-05	8.0E-06	0.053	4.2E-05	0.28
Geoduck whole body	Child	**1.2E-05**	**0.89**	3.5E-06	0.09	0.21	0.091	0.038	2.5E-06	9.7E-07	0.075	5.0E-06	0.39
Oyster	Adult	**1.4E-04**	**1.84**	2.9E-05	0.064	1	0.38	0.034	5.8E-05	8.5E-06	0.057	4.5E-05	0.3
Oyster	Child	**1.7E-05**	**2.68**	3.5E-06	0.09	1.5	0.54	0.048	7.0E-06	1.0E-06	0.08	5.4E-06	0.42
Intertidal sediment	Adult	**7.7E-06**	**0.02**	5.7E-06	0.013	5.9E-04	8.2E-04	2.5E-04	1.1E-06	1.5E-08	9.9E-05	9.1E-07	6.1E-03
Intertidal sediment	Child	**7.3E-06**	**0.23**	5.5E-06	0.14	6.4E-03	9.7E-03	2.9E-03	8.9E-07	1.4E-08	1.1E-03	8.7E-07	0.068
Total	**Adult**	9.1E-04	7.90	**2.5E-04**	**0.51**	**2.75**	**1.15**	**0.31**	**1.9E-04**	**1.2E-04**	**0.78**	**3.6E-04**	**2.41**
Total	**Child**	7.4E-05	7.62	**1.9E-05**	**0.50**	**2.62**	**1.14**	**0.30**	**1.6E-05**	**1.0E-05**	**0.80**	**2.9E-05**	**2.27**

Risk = cancer risk over a lifetime, HI = hazard index, HQ = hazard quotient, TEQ = toxic equivalence quotient.

* Inorganic arsenic.

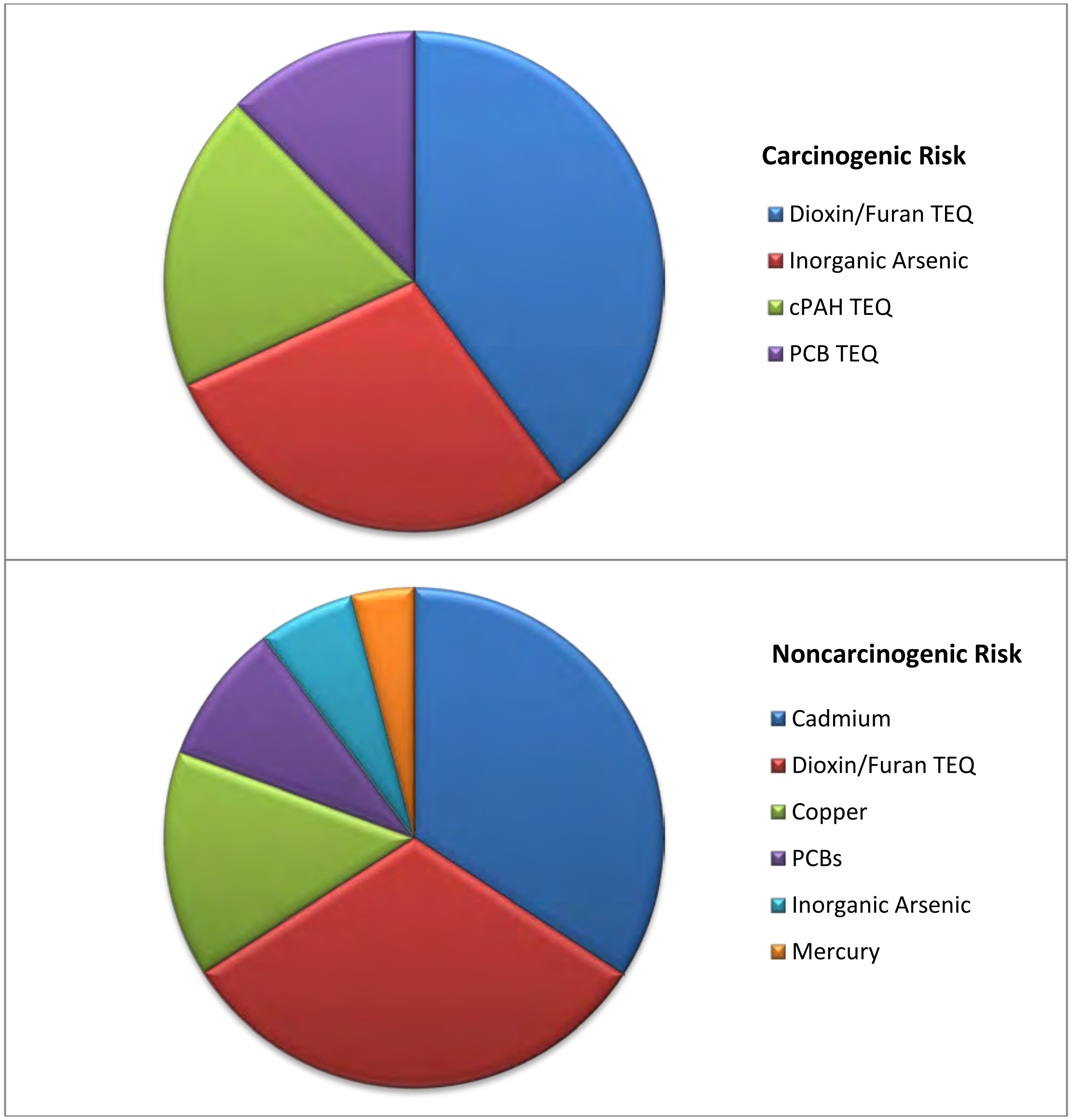

Figure 8-1. Relative Contributions to Human Health Risks in Port Gamble Bay

Table 8-7. Human Health Risks from Exposure to Natural Background Concentrations in Tissues

		All Chemicals		Arsenic*		Cadmium	Copper	Mercury	cPAH TEQ	Dioxin/Furan TEQ	
Medium	**Receptor**	**Risk**	**HI**	**Risk**	**HQ**	**HQ**	**HQ**	**HQ**	**Risk**	**Risk**	**HQ**
Clams	Adult	**2.1E-03**	**5.4**	1.9E-03	4.2	0.24	--	0.085	3.1E-05	1.3E-04	0.86
Clams	Child	**6.1E-05**	**2.0**	5.6E-05	1.5	0.084	--	0.085	9.2E-07	3.9E-06	0.30
Crab hepatopancreas	Adult	**1.7E-04**	**1.5**	1.4E-04	0.30	0.58	0.31	0.074	1.4E-06	3.6E-05	0.24
Crab hepatopancreas	Child	**1.7E-05**	**1.8**	1.4E-05	0.36	0.69	0.36	0.088	1.4E-07	3.6E-06	0.28
Crab muscle	Adult	**9.7E-05**	**0.84**	3.1E-05	0.067	0.092	0.094	0.19	7.6E-06	5.9E-05	0.40
Crab muscle	Child	**1.0E-05**	**0.94**	3.2E-06	0.084	0.011	0.12	0.23	8.0E-07	6.3E-06	0.49
Geoduck whole body	Adult	**1.4E-04**	**1.3**	--	--	0.26	0.054	0.080	8.1E-07	1.4E-04	0.91
Geoduck whole body	Child	**1.7E-05**	**1.8**	--	--	0.36	0.076	0.11	9.9E-08	1.7E-05	1.3
Total	**Adult**	**2.5E-03**	**9.1**	**2.1E-03**	**4.6**	**1.2**	**0.46**	**0.43**	**4.1E-05**	**3.7E-04**	**2.4**
Total	**Child**	**1.1E-04**	**6.5**	**7.3E-05**	**1.9**	**1.1**	**0.56**	**0.51**	**2.0E-06**	**3.1 E-05**	**2.4**

Risk = cancer risk over a lifetime, HI = hazard index, HQ = hazard quotient, TEQ = toxic equivalence quotient.

* Inorganic arsenic

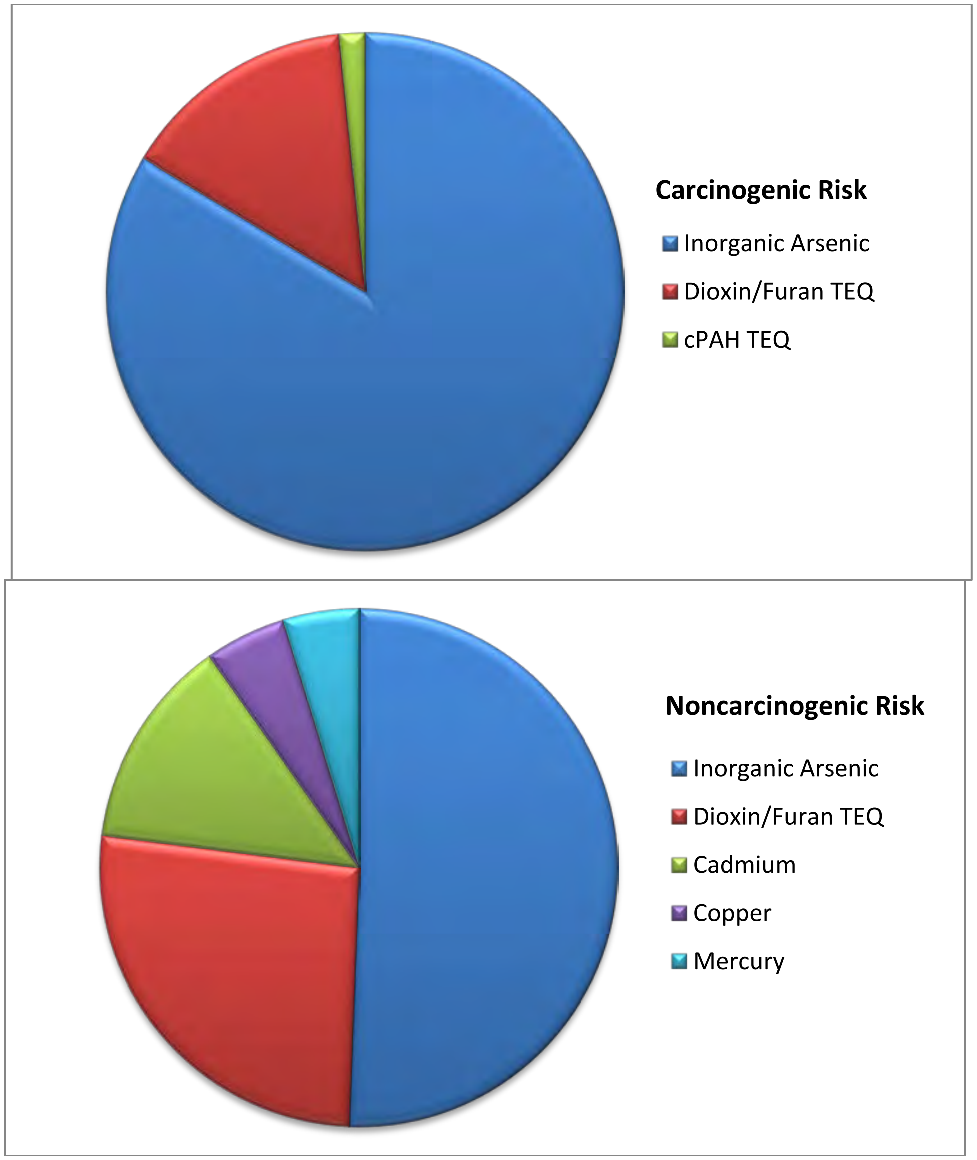

Figure 8-2. Relative Contributions to Human Health Risks in Natural Background Areas of Puget Sound

Table 8-8. Comparison of Human Health Risks between Natural Background Areas in Puget Sound and Port Gamble Bay Shellfish

Media	Receptor	Port Gamble with PCBs		Background without PCBs*	
		Risk	HI	Risk	HI
Clams	Adult	4.1E-04	3.1	2.1E-03	5.4
Clams	Child	1.2E-05	1.1	6.1E-05	2.0
Crab hepatopancreas	Adult	1.7E-04	1.6	1.7E-04	1.5
Crab hepatopancreas	Child	1.7E-05	1.9	1.7E-05	1.8
Crab muscle	Adult	9.0E-05	0.72	9.7E-05	0.84
Crab muscle	Child	9.5E-06	0.87	1.0E-05	0.94
Geoduck whole body	Adult	1.0E-04	0.64	1.4E-04	1.3
Geoduck whole body	Child	1.2E-05	0.89	1.7E-05	1.8
Oyster	Adult	1.4E-04	1.8	NA	NA
Oyster	Child	1.7E-05	2.7	NA	NA

NA – not available

Risk = cancer risk over a lifetime, HI = hazard index for noncarcinogenic chemicals.

* PCB congener data are not available for natural background tissues.

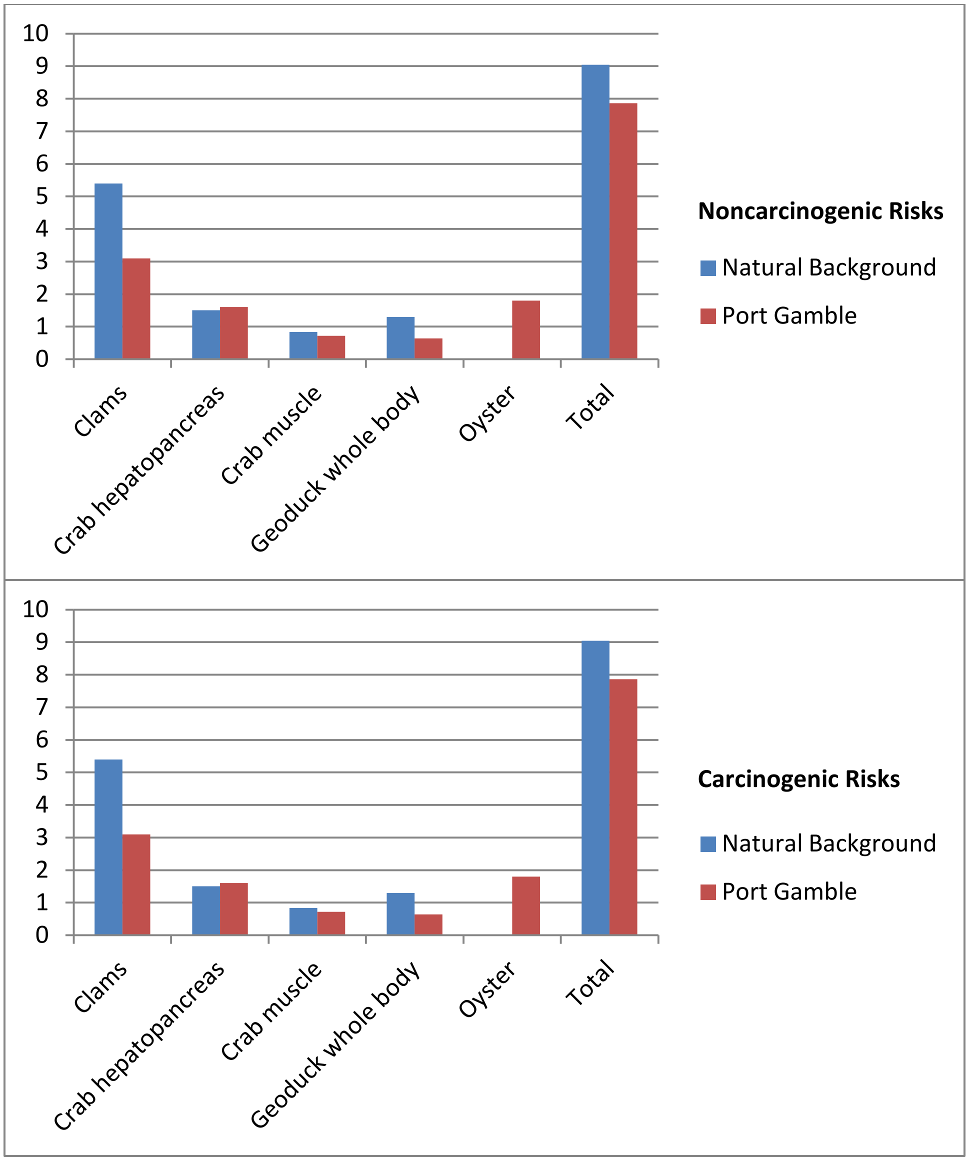

Figure 8-3. Comparison of Port Gamble Bay and Natural Background Risks in Shellfish Species

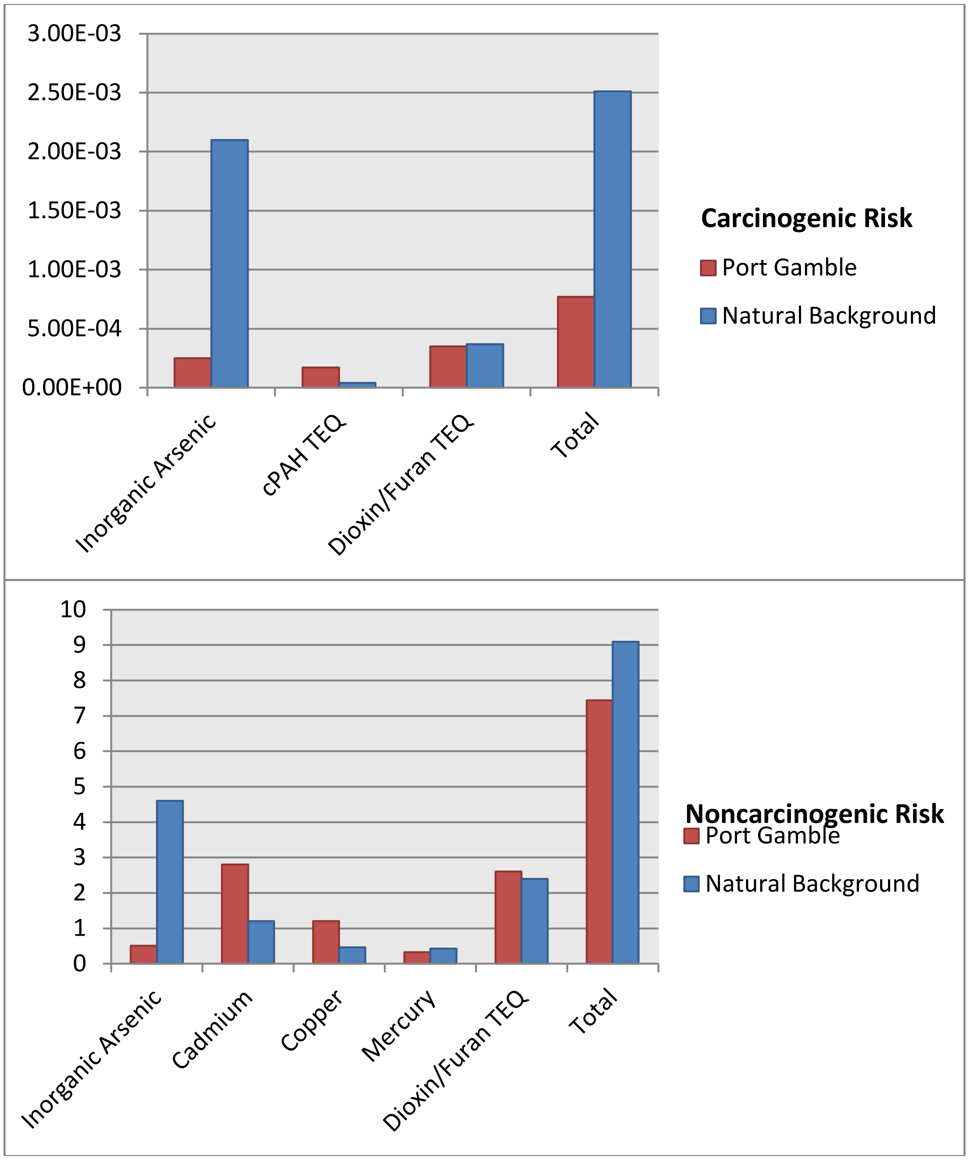

Figure 8-4. Comparison of Port Gamble Bay and Natural Background Risks among Chemicals

Natural geological concentrations of arsenic in the Cascade and Pacific Coast mountain ranges are quite high, leading to concentrations in soils, groundwater, surface water, and sediments in the Puget Sound area that frequently exceed MTCA or other risk-based levels for protection of human health (Huntting 1956; Johnson 2002; Ferguson and Johnson 2005; Thomas et al. 1997). Mining and smelting activities that tend to concentrate the arsenic and make it more bioavailable have exacerbated this problem in many areas around the Cascades; however, these activities do not appear to have impacted Port Gamble Bay.

In addition to natural sources, natural background as defined in MTCA includes globally distributed concentrations of chemicals such as dioxins/furans, PCBs, and PAHs. These chemicals are or have been in widespread use throughout the world and are distributed through regional atmospheric deposition, global weather patterns, and other large-scale transport pathways (e.g., bioconcentration in oceanic food resources in polar areas). Because MTCA is designed to deal with releases from individual facilities, these global concentrations are considered part of the background that cannot be addressed through cleanup of a single site. Instead, source control and use reduction programs as well as international treaties are tools that are used to eventually reduce this background to safe levels.

Finally, the majority of these calculated risks are associated with chemicals that were not detected in sediments or tissues at the site, even using very sensitive analytical methods. In these cases, a concentration was assumed for these chemicals based on their detection limits. However, these chemicals may or may not be present at the concentrations assumed, and if present, are at very low levels. As discussed in the uncertainty section below, this practice, along with the many other conservative approaches and assumptions used in the risk assessment, results in an upper bound estimate of risk. Risks at the site as well as in natural background areas of Puget Sound may be significantly lower than estimated here.

Because natural geologic and globally distributed concentrations of chemicals are likely to be similar in Port Gamble Bay and in other areas of Puget Sound, and because detection limits were used to estimate concentrations for so many of the chemicals of potential concern for both Port Gamble and Puget Sound sediments and tissues, the calculated risks for the two areas are quite similar. This indicates that for most CoCs for human health, local sources associated with individual facilities have not substantially increased concentrations in sediments or tissues over natural background. Carcinogenic PAHs and cadmium are exceptions, with risks that are significantly higher in Port Gamble Bay than in Puget Sound natural background areas.

8.5 Uncertainties

The following uncertainties in the human health risk evaluation are noted:

8.5.1 Data collection and analysis

- The majority of the calculated risks for dioxins/furans, PCB congeners, and cPAHs are associated with undetected values. Therefore, there is greater uncertainty regarding the actual concentrations and risks associated with these chemicals.
- Inorganic arsenic concentrations in Port Gamble Bay tissues were estimated based on percentages of total arsenic obtained from Ecology (2002). Actual percentages may vary; therefore, this approximation contributes to uncertainty in these results.
- There were only three composited crab samples and two composited geoduck samples from the bay. Because of these limited numbers of samples, the exposure estimates for crab and geoduck are relatively uncertain and may be biased high due to the statistical methods that are applied when there are fewer samples.

8.5.2 Exposure scenarios

- Survey data on the ingestion of shellfish by the Port Gamble S'Klallam Tribe are unavailable; shellfish ingestion rates were based on the Suquamish Tribe survey and were selected in consultation with the Port Gamble S'Klallam Tribe. The exposure assumptions for tribal fishermen may be low because finfish were not included in the exposure scenario, and because estimates of seafood consumption developed in recent years may have been suppressed due to concerns about contamination and reductions in fish and shellfish resources available for harvest. On the other hand, shellfish ingestion rates based on data collected for a short period of time (less than a week) may overestimate the amount of shellfish people eat on a regular basis for the longer time periods (years) considered in this risk assessment.
- Shellfish consumption rates based on the Suquamish Tribal survey likely represent overestimates for the general population. Information compiled by the EPA (EPA 2011) indicates that recreational fishermen using Port Gamble Bay are likely to be exposed to lower amounts of these chemicals in shellfish due to much lower consumption rates.

8.5.3 Toxicity Values

- The models used by EPA to develop cancer potency factors rely on information from population groups with high exposures (such as industrial workers) and/or from laboratory studies with animals. This information is used to estimate risks for the general human population. There are many uncertainties associated with extrapolating from high to low exposures and from animals to humans. The CSFs used in this assessment were developed by EPA using methods that are designed to provide an upper bound estimate of cancer risks.
- In 2010, EPA completed draft CSFs for arsenic and dioxins/furans and distributed these evaluations for scientific peer review. In both cases, the draft CSFs are somewhat more stringent than the values used to prepare this risk assessment. However, the differences between the current and draft values are not large enough to alter the overall risk assessment conclusions.
- The non-cancer risk models used by EPA to develop reference doses also rely on information from population groups with high exposures and/or from laboratory studies with animals. As with cancer models, there are many uncertainties associated with extrapolating from high to low exposures and from animals to humans. EPA uses methods that are designed to provide a

conservative estimate of a "no effects" or "safe" level. EPA is currently evaluating non-cancer studies for dioxins, arsenic, and PCBs. With respect to dioxins, EPA has announced that it plans to adopt a new oral reference dose that is slightly lower (slightly more stringent) than the value used for this risk assessment. However, the difference between the current and draft value is not large enough to alter the overall risk assessment conclusions.

8.5.4 Overall Risk Estimates

- Ecology has used a wide range of information and assumptions to prepare the human health risk assessment. Taking into account all of the uncertainties described above, Ecology believes that the risk estimates presented in this section are upper-bound estimates.

8.6 Summary

The following conclusions can be drawn from the human health risk assessment:

- Risks associated with arsenic, cPAHs, PCBs, and dioxins/furans in Port Gamble Bay shellfish exceed MTCA/SMS threshold risk levels. The risk associated with cadmium slightly exceeds the MTCA/SMS risk threshold, copper was approximately equal to the threshold, and mercury was below the threshold.
- Most of the risks associated with these chemicals are associated with natural background concentrations or undetected chemicals. Overall health risks in Port Gamble Bay are similar to those in natural background areas in Puget Sound.
- cPAHs and cadmium in shellfish have higher risks in Port Gamble Bay than in natural background areas of Puget Sound, while risks associated with arsenic are lower in Port Gamble Bay. Risks associated with dioxins/furans are approximately similar to natural background areas of Puget Sound.
- Arsenic is also associated with low-level risks due to exposure to intertidal sediment during clam-digging or other beach activities. These risks are believed to be due to natural concentrations of arsenic in the sediments.

Section 9 provides a statistical comparison of sediment and tissue data to more definitively determine which of these chemicals are elevated in Port Gamble Bay compared to Puget Sound natural background concentrations.

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9.0 NATURAL BACKGROUND COMPARISONS

Natural background comparisons are an important component of developing cleanup standards for the site and identifying site boundaries and SMAs. The cleanup standard is defined as the highest of 1) risk-based concentrations, 2) natural background concentrations, and 3) practical quantitation limits (PQLs). Section 8 addresses human health risk, this section addresses natural background comparisons, and Section 11 describes how these are combined with PQLs to identify contaminants of concern and select site-specific cleanup levels.

Human health and/or environmental risks may exist at natural background concentrations. However, if site concentrations are statistically similar to natural background concentrations, it can be inferred that concentrations are not elevated at the site due to site-related sources, and that risks at the site due to these chemicals are similar to risks throughout Puget Sound due to natural sources as well as regional and global sources of anthropogenic compounds.

Statistical comparisons between Port Gamble Bay and Puget Sound natural background concentrations in sediments and tissues were conducted only for the CoPCs identified for human health, because levels of concern to benthic organisms are generally higher than background and environmental adverse effects can be evaluated using existing chemical and biological standards.

Natural background comparisons can be done in a variety of ways. Comparison of the central tendencies (means or medians) of the distributions is useful for evaluating whether the distributions as a whole are different from one another. Comparing the highest concentrations in the distributions (upper tails) is also useful because even if most of the distribution is the same, it may identify individual stations that are higher than normal. The following discussion uses both types of evaluations to compare the distributions of concentrations in Port Gamble Bay to natural background areas.

Following the most recent statistical guidance for natural background comparisons (RSET 2008), non-parametric analyses were conducted in ProUCL for distributional comparisons between site data and natural background data, using comparison of medians tests (i.e., either the Mann-Whitney rank or Gehan score test, depending on whether non-detects were present in the data set). Graphical comparisons in the form of overlaid empirical cumulative distribution function plots (ECDF plots) were also generated to facilitate comparison of site and natural background distributions for each chemical and sample type. The Quantile test was used to compare the upper tails of the two distributions, and was performed only when the cumulative distribution plots indicated that any Port Gamble concentrations above the median exceeded natural background.

Statistical analyses were performed using EPA's ProUCL (EPA 2010) software, or following ProUCL methods in R (R Development Core Team 2011). The PCB, dioxin/furan, and cPAH TEQs were calculated by summing multiple chemical values using KM summation methods where appropriate (Helsel 2010) or substitution at one-half the detection limit. The KM sum was only calculated when the frequency of detection was 50% or greater across all congeners or individual chemicals within a sample. TEQs calculated by KM were flagged if the highest or lowest TECs were non-detects and were treated as detected to avoid being biased low by the KM estimation method. When the frequency of detection was less than 50%, substitution at one-half the detection limit was used for all non-detects.

9.1 Sediments

Natural background sediment data were obtained from the Puget Sound sediment database developed from the EPA Bold survey (DMMP 2009). Fifteen stations were selected from the Bold survey data set from the three established reference areas closest and most geohydrologically similar to Port Gamble Bay. The following set of stations was selected as representative of natural background (as defined in MTCA):

- Holmes Harbor: R_HOL_0, R_HOL_1, R_HOL_3, R_HOL_4, R_HOL_7
- Dabob Bay: R_DAB_0, R_DAB_1, R_DAB_2, R_DAB_5, and R_DAB_7_C
- Carr Inlet: R_CAR_0, R_CAR_1, R_CAR_4, R_CAR_5, R_CAR_6_C

One station, R_CAR_5, had a dioxin/furan TEQ that was relatively high (5.1 ng/kg TEC). This station was not a statistical outlier for dioxin/furan TEQ relative to the other 14 stations in this natural background data set using a skewed distribution such as gamma or lognormal, typical of environmental data sets. However, evaluations involving dioxin/furan TEQs in natural background sediments were done both with and without this sample to assess its influence on the overall conclusions. This station was not a statistical outlier for any other chemical being evaluated.

Summary statistics for site and natural background sediment data for metals, total PCBs, and the cPAH, dioxin/furan, and PCB TEQs are presented in Table 9-1. Results of the statistical comparisons between site and natural background subtidal sediments are presented in Table 9-2. All sediment data are expressed in units of dry weight. Conclusions are summarized below:

- Arsenic was not widely detected in Port Gamble Bay subtidal sediment samples with only 31% (21/67) of the subtidal sediments having detected concentrations. The median concentration in Port Gamble Bay was 3.9 mg/kg compared to 6.3 mg/kg in natural background sediments. Statistical tests indicate that the Port Gamble Bay subtidal sediments were not significantly different from natural background for (p = 1.0, Table 9-2). The cumulative distribution plots (Figure 9-1) illustrate that the arsenic concentrations in both the subtidal and intertidal sediments of Port Gamble Bay are below natural background, with the exception of one historical sample (DV-01 sampled 9/18/2003 by Parametrix) with a detected concentration of 25.4 mg/kg, and four more recent samples (PGSS-16 from 2008, and 110928-01, -02, and -04 from 2011) all reported as undetected at 20 mg/kg.

- Cadmium was frequently detected in Port Gamble Bay with 93% (62/67) of the subtidal sediments and 48% (10/21) of the intertidal sediments having detected concentrations. The median cadmium concentration in Port Gamble Bay was statistically higher than the median in natural background sediment samples (p = 0.001, Table 9-2). The Port Gamble median concentration was 1.3 mg/kg, while the natural background median concentration was 0.39 mg/kg. The Quantile test could not be completed because of non-detected values in the upper tail of the site distribution. However, the concentration for Port Gamble sample BW-22 (3.1 mg/kg) exceeded all background concentrations. The distribution of cadmium concentrations in subtidal sediments exceeded natural background, while intertidal concentrations were all below natural background (Figure 9-1).
- Copper was detected in every Port Gamble Bay sediment sample. Copper in Port Gamble Bay sediments appears to be within natural background concentrations, with a Port Gamble Bay median concentration of 27 mg/kg and a natural background median concentration of 25 mg/kg. The median copper concentration from Port Gamble was not significantly different from natural background (p = 0.45, Table 9-2) and the cumulative distribution plots are nearly identical (Figure 9-1). The distribution of intertidal concentrations of copper was also similar to that of natural background (Table 9-1 and Figure 9-1).
- Mercury was detected in 52% (33/64) of the Port Gamble Bay subtidal sediments and only 14% (3/21) of the intertidal sediments. The mercury concentrations found in Port Gamble Bay sediments were well below natural background concentrations (Figure 9-1). The Port Gamble Bay median concentration was 0.05 mg/kg, while the natural background median concentration was 0.10 mg/kg. The site distribution was not significantly different from natural background (p = 0.99, Table 9-2).
- Carcinogenic PAH TEQs in Port Gamble Bay sediments were clearly elevated above Puget Sound natural background (Figure 9-1) with significant differences for both the median and the upper tail of the distribution (p < 0.001, Table 9-2). The median cPAH TEQ value for subtidal sediments from Port Gamble Bay was 30 µg/kg, while the median for the intertidal sediments was 20 µg/kg. The Puget Sound natural background median cPAH TEQ value was 3.6 µg/kg. The highest concentration was found at intertidal station PG11-MS-20 (340 µg/kg TEQ). However on average, the concentrations in Port Gamble intertidal sediments were lower than those in the subtidal areas.
- For PCB Aroclors, both Port Gamble Bay and natural background sediments had very few detections. Port Gamble Bay had a 5% (3/59) detection frequency in subtidal sediments, with a KM mean of 7.1 µg/kg. Puget Sound natural background sediments had a 33% (5/15) detection frequency and a KM mean of 6.0 µg/kg (Table 9-1). The median of the Port Gamble subtidal sediments was not significantly different from natural background (p = 0.98, Table 9-2) and the distribution of total PCBs in Port Gamble sediments was also within natural background (Figure 9-1), except for one extreme concentration (158 µg/kg) at Station DV-02 (Parametrix 2003).
- PCB congeners were analyzed only in intertidal samples from Port Gamble, collected both near the former mill site and from intertidal areas throughout the Bay. Both the median and the upper tail of the PCB congener TEQs in Port Gamble Bay intertidal sediments were within

natural background ($p > 0.05$, Table 9-2 and Figure 9-1). The Puget Sound natural background median PCB TEQ value was 0.047 ng/kg, greater than the median PCB TEQ values for Port Gamble Bay intertidal sediments (0.028 ng/kg). There were two intertidal stations with elevated PCB TEQs (BW-27 at 0.20 ng/kg, and BW-32 at 0.11 ng/kg), but the remaining 14 intertidal stations were below the natural background median value.

- The median dioxin/furan TEQ in Port Gamble subtidal sediments was significantly higher than Puget Sound natural background values ($p = 0.011$, Table 9-2). The median dioxin/furan TEQ value for subtidal sediments from Port Gamble Bay was 2.7 ng/kg, while the median for the intertidal sediments was 0.53 ng/kg. The Puget Sound natural background median dioxin/furan TEQ value was 1.1 or 1.0 ng/kg, with and without CAR-5, respectively. The Quantile test comparing the upper tails of the Port Gamble distribution with the natural background distribution (excluding CAR-5) was significant ($p < 0.05$, Table 9-2), indicating that the upper tail of the Port Gamble distribution is significantly greater than natural background. The cumulative distribution plots (Figure 9-1) illustrate that the distribution of dioxin/furan TEQs in Port Gamble subtidal sediments is consistently elevated above natural background, while the intertidal TEQs only exceed natural background in the upper ends of the distribution. There were 15 Port Gamble stations with TEQs that exceeded the maximum background TEQ (2.1 pg/g, excluding CAR-5): 11 subtidal stations plus four intertidal stations from the former mill area. The most extreme dioxin/furan TEQ value was reported for intertidal station MS-20 with a value of 16 pg/g, approximately 2.5 times the next highest TEQ value.

Table 9-1. Comparison of Concentrations in Port Gamble Bay Subtidal Sediments to Puget Sound Natural Background Sediments

Endpoint	Location	Valid Data Pts	No. of NDs	No. of Detects	% Detected	Min Detected	Mean Detected	Max Detected	Max Non-Detect	Overall Median (KM)[2]	Overall Mean (KM)[2]
Arsenic	Background	15	0	15	100%	1.6	6.9	18	NA	6.3	6.9
	Intertidal	21	0	21	100%	0.92	2.3	4.1	NA	2.3	2.3
	Subtidal	67	46	21	31%	2.3	6.3	25	20	3.9	4.7
Cadmium	Background	15	0	15	100%	0.032	0.56	2.8	NA	0.39	0.56
	Intertidal	21	11	10	48%	0.10	0.47	1.1	0.10	NA	0.28
	Subtidal	67	5	62	93%	0.20	1.3	3.1	2.6	1.3	1.2
Copper	Background	15	0	15	100%	3.3	26	57	NA	25	26
	Intertidal	21	0	21	100%	5.9	20	48	NA	17	20
	Subtidal	67	0	67	100%	3.4	24	53	NA	27	24
Mercury	Background	15	5	10	67%	0.072	0.16	0.26	0.062	0.10	0.13
	Intertidal	21	18	3	14%	0.020	0.033	0.060	0.030	NA	0.022
	Subtidal	64	31	33	52%	0.030	0.088	0.13	0.10	0.050	0.061
Dioxin TEQ	Background	15	NA	NA	--	0.24	1.3	5.1	NA	1.1	1.3
KM+HalfDL	Background-Ex[1]	14	NA	NA	--	0.24	1.0	2.1	NA	1.0	1.0
pg/g, dw	Intertidal	16	NA	NA	--	0.16	2.1	16	NA	0.53	2.1
	Subtidal	19	NA	NA	--	0.34	3.1	6.5	NA	2.7	3.1
cPAH TEQ	Background	15	NA	NA	--	1.4	4.9	13	NA	3.6	4.9
µg/kg, dw	Intertidal	21	NA	NA	--	1.5	42	340	NA	20	42
	Subtidal	66	NA	NA	--	5.2	52	280	NA	30	52
PCB Aroclors	Background	15	10	5	33%	2.1	12	31	17	2.9	6.0
	Intertidal	0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Subtidal	59	56	3	5%	4.3	59	160	21	NA	7.1
PCB TEQ	Background	15	NA	NA	--	0.018	0.047	0.093	NA	0.047	0.047
pg/g, dw	Intertidal	16	NA	NA	--	0.0059	0.043	0.20	NA	0.028	0.043
	Subtidal	0	NA	NA	NA	NA	NA	NA	NA	NA	NA

[1]The "Background-Ex" group excludes station CAR-5.

[2] The median cannot be estimated when the detection frequency is too low; estimates of the mean become more uncertain as the percentage of non-detects increases above 50%.

Table 9-2. Distributional Comparisons between Subtidal Sediments in Port Gamble Bay and Puget Sound Natural Background

Endpoint	Test	*p*	Conclusion
Arsenic	Gehan Test	0.997	Site ≤ background
Cadmium	Gehan Test Quantile	0.001	Site > background Nondetect values in the upper tail; cannot complete test
Copper	Mann-Whitney	0.45	Site ≤ background
Mercury	Gehan Test	0.99	Site ≤ background
Dioxin TEQ **Excluding CAR-5**[1]	Mann-Whitney Quantile Test	0.011	Site > background Site > background excluding CAR-5
cPAH TEQ	Mann-Whitney Quantile	2E-09	Site > background Site > background
Total PCBs **(sum of Aroclors)**	Gehan Test[2] Quantile	0.977	Site ≤ background Nondetect values in the upper tail; cannot complete test
PCB TEQ (intertidal sediments)	Mann-Whitney Quantile	0.931	Site ≤ background Site ≤ background

Mann-Whitney and Gehan Test null hypothesis: site ≤ background.

[1]CAR-5 was a high value in the background data set for dioxins. Comparisons were done with and without this sample for dioxin only.

[2] Score tests are not greatly affected by single high values.

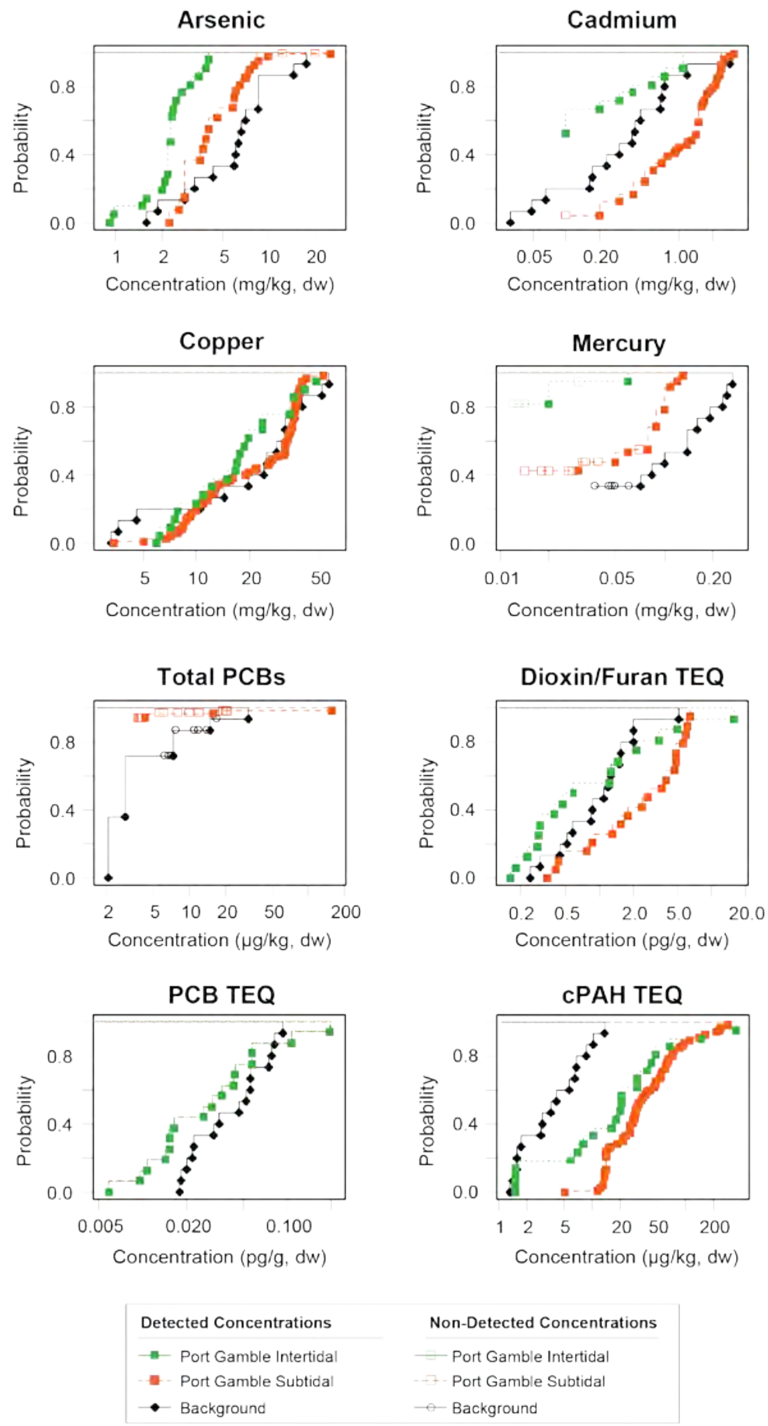

Figure 9-1. Empirical cumulative distribution plots for sediments

9.2 Tissue Samples

Concentrations in shellfish tissue collected from EPA or Ecology-recognized natural background locations were assembled for the selected CoCs. Natural background data were identified for:

- Dioxins/furans in crabs (muscle tissue and hepatopancreas), clams, geoducks (whole body), and oysters
- Arsenic in crabs (muscle tissue and hepatopancreas) and clams
- Cadmium in crabs (muscle tissue and hepatopancreas), clams, and geoducks
- Copper in crabs (muscle tissue and hepatopancreas) and geoducks
- Mercury in crabs (muscle tissue and hepatopancreas), clams, and geoducks
- PAH TEQs in crabs (muscle tissue and hepatopancreas), clams, and geoducks
- Total PCBs in crabs (muscle tissue and hepatopancreas) and clams

Natural background tissue data are summarized and compared to Port Gamble Bay tissue concentrations in Tables 9-3 and 9-4. Complete data tables for natural background tissue concentrations are provided in Appendix C (all tissue data are reported in wet weight). The following data sets were compiled to determine natural background tissue concentrations:

- Data on dioxin TEQs in crabs were available from Ecology's EIM database for natural background locations from Dungeness Bay, Freshwater Bay, Skagit Bay, and Padilla/Fidalgo Bay (PSEP 1991a, Malcolm Pirnie 2007, Ecology 2000). Three samples from Pedder Bay that were used in the previous Port Gamble RI were also included. Each tissue sample was made up of 1–5 individual crabs per sample. The TEQs included non-detected values at one-half the RL. In total, there were data for 26 hepatopancreas and 27 muscle tissue samples. Because not all of these TEQs were calculated in the same manner and some had elevated detection limits, comparisons using these data are of limited value for decision making. Additional background data are anticipated to be collected in the near future and will be substituted once available.
- Data on dioxin TEQs in clams and geoducks from natural background locations were also available from Ecology's EIM database. Two littleneck clam composite samples (10–20 individuals per sample) were collected from Salsbury Point in 2003 (Parametrix 2003b). Seven geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay (Malcolm Pirnie 2007), and at a natural background site for the 2008 Port Angeles Harbor Sediment Investigation (Ecology 2009).
- Data on inorganic arsenic in clams collected from natural background locations were taken from EPA and Ecology-approved data reports for the RI for the LDW site (Windward 2005a, Windward 2006). Clams were collected from bays on Bainbridge Island, Vashon Island, Dungeness National Wildlife Refuge, and Seahurst Park. A total of 24 composite samples were available, each composite consisting of 10–28 individual clams with either exclusively eastern softshell clams (*Mya arenaria*) or mixed species.

- Data on inorganic arsenic in crabs collected from natural background locations were taken from an EPA and Ecology-approved data report for the RI for the LDW site (Windward 2005b). Crabs were collected from Blake Island and East Passage; data from a total of 12 composite muscle tissue samples were available, six of Dungeness crab and six of slender crab. Data were also available from a total of four composite hepatopancreas samples, two of Dungeness crab and two of slender crab.
- Data on cadmium in clams and geoducks from natural background locations were available from Ecology's EIM database. Two littleneck clam composite samples and 128 butter clam composites were collected from natural background locations between 1998 and 2010 (King County 2000–2010). Specifics on the number of individual clams per composite were not available. Six geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay for the 2002 Former Rayonier Mill Site RI (Malcolm Pirnie 2007).
- Data on cadmium in crabs collected from natural background locations were taken from the 2002 Rayonier Mill Site RI (Malcolm Pirnie 2007). Six Dungeness crabs were collected from Dungeness Bay and Freshwater Bay; data were available for muscle and hepatopancreas tissues from the six individual crabs.
- Data on copper in geoducks from natural background locations were available from Ecology's EIM database. Six geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay (Malcolm Pirnie 2007) and one was collected near Port Angeles for the Port Angeles Harbor Sediment Investigation Study (Ecology 2009).
- Data on copper in crabs collected from natural background locations were taken from the 2002 Rayonier Mill Site RI (Malcolm Pirnie 2007). Six Dungeness crabs were collected from Dungeness Bay and Freshwater Bay; data were available for muscle and hepatopancreas tissues from the six individual crabs.
- Data on mercury in clams and geoducks from natural background locations were available from Ecology's EIM database. A total of 128 butter clam composites were collected from natural background locations between 1998 and 2010 (King County 2000–2010). Specifics on the number of individuals per composite were not available. Six geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay (Malcolm Pirnie 2007) and one was collected near Port Angeles for the Port Angeles Harbor Sediment Investigation Study (Ecology 2009).
- Data on mercury in crabs collected from natural background locations were taken from the 2002 Rayonier Mill Site RI (Malcolm Pirnie 2007) and the 1999 Padilla Bay Shellfish Screening for Metals and Organics (Ecology 2000). Dungeness crabs were collected from Dungeness Bay, Freshwater Bay, off Samish Island and near Hat Island; data were available for a total of eight muscle tissues (six samples of individual crabs and two composites with five crabs per sample) and six hepatopancreas tissues from individual crabs.
- Data on carcinogenic PAH TEQs in clams and geoducks from natural background locations were taken from Ecology's EIM database for samples from EPA-approved background locations for the LDW RI. A total of 14 littleneck clam composites were available from locations at Salsbury

Point, Port Washington Narrows, and Keyport (Ecology 2002, Parametrix 2003b, and URS 2009). Composite samples were comprised of 10–20 or an unspecified number of individuals per sample. Seven geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay (Malcolm Pirnie 2007) and a reference site near Port Angeles (Ecology 2009). Carcinogenic PAH TEQs were used as reported.

- Data on carcinogenic PAH TEQs in crabs from natural background locations were taken from the 2002 Rayonier Mill Site RI (Malcolm Pirnie 2007) and the 1999 Padilla Bay Shellfish Screening for Metals and Organics (Ecology 2000). Dungeness crabs were collected from Dungeness Bay, Freshwater Bay, off Samish Island and near Hat Island; data were available for a total of eight muscle and seven hepatopancreas tissue samples with 1–5 individual crabs per sample. Carcinogenic PAH TEQs were used as reported.
- PCB data for natural background tissue samples were only available as total PCBs, calculated as the sum of Aroclors using methods described in the SMS. Clams were collected from natural background locations near Gorsuch Creek on Vashon Island (King County 2005) and Salsbury Point (Parametrix 2003). A total of four butter clam and two littleneck clam composite samples were available, each sample comprised of 8–20 individuals, or an unspecified number of individuals per composite. All samples had non-detected concentrations of total PCBs.
- Total PCBs in crabs from natural background locations were taken from the 2006 Rayonier Mill Site Phase 2 Addendum RI (Malcolm Pirnie 2007) and the 1999 Padilla Bay Shellfish Screening for Metals and Organics (Ecology 2000). Dungeness crabs were collected from Dungeness Bay, Freshwater Bay, off Samish Island and near Hat Island; data were available for a total of 17 muscle and 15 hepatopancreas tissue samples with 1–5 individual crabs per sample.

Table 9-3. Summary of Port Gamble Bay and Puget Sound Natural Background Tissue Concentrations – Metals and PCB Aroclors

Endpoint	Tissue	Location	Valid Data Pts	Number of NDs	Number of Detects	% Detected	Min Detected	Mean Detected	Max Detected	Max Non-Detect	Overall Median (KM)[a]	Overall Mean (KM)[a]
Arsenic, Inorganic mg/kg, ww	Clam	Background	24	0	24	100%	0.044	0.21	0.62	--	0.11	0.21
		Port Gamble	28	8	20	71%	0.012	0.030	0.060	0.012	0.024	0.025
	Crab – muscle	Background	12	0	12	100%	0.010	0.021	0.040	--	0.020	0.021
		Port Gamble	3	0	3	100%	0.010	0.011	0.014	--	0.010	0.011
	Crab – hepato	Background	4	0	4	100%	0.080	0.19	0.34	--	0.080	0.19
		Port Gamble	3	0	3	100%	0.0080	0.013	0.016	--	0.016	0.013
	Geoduck	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	2	0	2	100%	0.012	0.018	0.024	--	0.024	0.018
	Oyster	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	10	1	9	90%	0.012	0.016	0.024	0.012	0.012	0.016
Cadmium mg/kg, ww	Clam	Background	130	0	130	100%	0.041	0.065	0.255	--	0.061	0.065
		Port Gamble	28	3	25	89%	0.040	0.33	0.71	0.040	0.29	0.30
	Crab – muscle	Background	6	1	5	83%	0.006	0.009	0.013	0.007	0.007	0.0087
		Port Gamble	3	2	1	33%	0.040	0.040	0.04	0.04	--	0.04
	Crab - hepato	Background	6	0	6	100%	1.3	1.8	2.4	--	1.5	1.8
		Port Gamble	3	0	3	100%	0.34	0.87	1.44	--	0.83	0.87
	Geoduck	Background	6	0	6	100%	0.16	0.26	0.34	--	0.30	0.26
		Port Gamble	2	0	2	100%	0.19	0.19	0.19	--	0.19	0.19
	Oyster	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	10	0	10	100%	0.96	1.2	1.5	--	1.2	1.2
Copper	Clam	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	28	0	28	100%	0.91	3.8	26	--	2.6	3.8
	Crab - muscle	Background	6	0	6	100%	3.6	4.2	5.1	--	4.0	4.2
		Port Gamble	3	0	3	100%	3.8	6.0	8.7	--	5.7	6.0
	Crab - hepato	Background	6	0	6	100%	5.8	29	55	--	16	29
		Port Gamble	3	0	3	100%	4.0	9.1	19	--	4.1	9.1
	Geoduck	Background	7	0	7	100%	1.6	2.2	3.3	--	2.1	2.2
		Port Gamble	2	0	2	100%	2.9	3.1	3.3	--	3.3	3.1
	Oyster	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	10	0	10	100%	4.0	11	34	--	8.4	11
Mercury mg/kg, ww	Clam	Background	128	2	126	98%	0.0032	0.0070	0.014	0.0041	0.0063	0.0070
		Port Gamble	28	7	21	75%	0.0050	0.0080	0.016	0.010	0.0060	0.0073
	Crab -	Background	8	0	8	100%	0.031	0.056	0.086	--	0.051	0.056

Table 9-3. Summary of Port Gamble Bay and Puget Sound Natural Background Tissue Concentrations – Metals and PCB Aroclors

Endpoint	Tissue	Location	Valid Data Pts	Number of NDs	Number of Detects	% Detected	Min Detected	Mean Detected	Max Detected	Max Non-Detect	Overall Median (KM)[a]	Overall Mean (KM)[a]
	muscle	Port Gamble	3	0	3	100%	0.027	0.037	0.047	--	0.036	0.037
	Crab - hepato	Background	6	0	6	100%	0.048	0.061	0.095	--	0.054	0.061
		Port Gamble	3	0	3	100%	0.02	0.026	0.03	--	0.028	0.026
	Geoduck	Background	7	1	6	86%	0.013	0.024	0.042	0.0086	0.019	0.022
		Port Gamble	2	0	2	100%	0.01	0.01	0.01	--	0.01	0.01
	Oyster	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	10	0	10	100%	0.010	0.011	0.014	--	0.010	0.011
Total PCBS Aroclor Sum (U = 0) µg/kg, ww	Clam	Background	6	6	0	0%	--	--	--	5.0	--	--
		Port Gamble	19	18	1	5%	4.2	4.2	4.2	12	--	4.2
	Crab - muscle	Background	17	0	17	100%	0.44	0.87	1.92	--	0.80	0.87
		Port Gamble	1	1	0	0%	--	--	--	8	--	--
	Crab - hepato	Background	15	0	15	100%	8.8	21	50	--	15	21
		Port Gamble	1	1	0	0%	--	--	--	20	--	--
	Geoduck	Background	0	--	--	--	--	--	--	--	--	--
		Port Gamble	2	2	0	0%	--	--	--	4	--	--
	Oyster	Background	0	--	--	--	--	--	--	--	--	--
		Port Gamble	10	8	2	20%	7.2	14.1	21	9.9	--	8.58

-- Insufficient data to calculate this statistic.

[a] Overall mean and median calculated based on all detected and non-detected data using Kaplan-Meier (KM) methods for censored data sets.

Table 9-4. Summary of Port Gamble Bay and Puget Sound Natural Background Tissue Concentrations – PAH, PCB, and Dioxin/Furan TEQs[a]

Endpoint	Tissue	Location	Valid Data Pts	Minimum	Median	Mean	Maximum
PAH TEQ µg/kg, ww	Clam	Background	14	0.11	1.0	0.85	1.3
		Port Gamble	28	0.35	0.51	1.7	8.2
	Crab - muscle	Background	8	0.11	0.11	0.41	1.6
		Port Gamble	3	0.35	0.35	1.4	3.5
	Crab - hepato	Background	7	0.11	0.11	0.23	0.90
		Port Gamble	3	0.35	0.35	1.4	3.4
	Geoduck	Background	7	0.069	0.11	0.12	0.17
		Port Gamble	2	3.4	3.5	3.5	3.5
	Oyster	Background	0	--	--	--	--
		Port Gamble	10	0.82	1.8	4.3	19
PCB TEQ pg/g, ww	Clam	Background	0	--	--	--	--
		Port Gamble	11	0.022	0.034	0.043	0.080
	Crab - muscle	Background	0	--	--	--	--
		Port Gamble	3	0.033	0.044	0.046	0.063
	Crab - hepato	Background	0	--	--	--	--
		Port Gamble	3	0.81	0.82	1.1	1.7
	Geoduck	Background	0	--	--	--	--
		Port Gamble	2	0.057	0.062	0.062	0.067
	Oyster	Background	0	--	--	--	--
		Port Gamble	2	0.070	0.071	0.071	0.071
Dioxin/furan TEQ, pg/g, ww	Clam	Background	2	0.23	0.25	0.25	0.27
		Port Gamble	11	0.077	0.083	0.14	0.37
	Crab - muscle	Background	27	0.027	0.067	0.22	1.4
		Port Gamble	3	0.083	0.095	0.18	0.37
	Crab - hepato	Background	26	0.18	0.52	0.69	2.6
		Port Gamble	3	0.94	1.5	1.5	2.2
	Geoduck	Background	7	0.21	0.24	0.41	1.4
		Port Gamble	2	0.34	0.34	0.34	0.35
	Oyster	Background	0	--	--	--	--
		Port Gamble	2	0.37	0.37	0.37	0.37

-- Insufficient data to calculate this statistic.

[a] TEQs shown in this table were calculated using the method described in Section 8.2.4. Using this method, all final estimated TEQ values are treated as detected; therefore, summary statistics can be calculated on the estimated TEQs even if most or all of the component congeners were undetected.

Results of the statistical comparisons are presented in Table 9-5 and are graphically shown in Figures 9-2 through 9-5. A summary of the natural background comparisons for tissues is presented below.

9.2.1 Clam Tissues

- Concentrations of inorganic arsenic from Port Gamble clam tissues did not exceed natural background concentrations.
- Cadmium concentrations in Port Gamble clam tissues were significantly elevated above natural background (both the median and upper percentile were significantly greater than natural background, $p < 0.05$). The median concentration for Port Gamble was 0.29 mg/kg, substantially higher than the natural background median concentration of 0.061 mg/kg.
- There were no copper concentrations for clam tissues from natural background locations to which the Port Gamble tissues could be compared.
- Concentrations of mercury in Port Gamble clam tissues were generally at or below natural background concentrations. One Port Gamble clam tissue had mercury at a concentration exceeding the maximum background concentration of 1.4 mg/kg: 1.6 mg/kg at station PG11-BW-32-LN.
- The median concentration of cPAH TEQs in Port Gamble clam tissues was 0.51 µg/kg, lower than the natural background median concentration of 1.0 µg/kg. The Port Gamble distribution of cPAH TEQs in clam tissues was fairly skewed, and the upper percentile of the distribution exceeded natural background ($p < 0.05$). There were nine stations with concentrations of cPAH TEQs in clam tissues exceeding the maximum background concentration of 1.3 µg/kg. These elevated Port Gamble concentrations ranged from 1.7 µg/kg (Mill area station B3_C_PGST_100429) to 8.2 µg/kg (Mill area station PG11-MS-20-LN).
- PCBs (sum of Aroclors) were detected in only one clam tissue sample (4.2 µg/kg at Station B-2 near the mill). Detection limits for the natural background clam samples ranged from 2.5–5 U µg/kg, while detection limits for the Port Gamble clam tissues ranged from 3.9–12 U µg/kg. The only detected Port Gamble concentration was below the maximum natural background non-detected value.
- Dioxin TEQs in Port Gamble clam tissues were generally at or below available natural background concentrations. Two Port Gamble clam tissues had dioxin/furan TEQ values exceeding the maximum background of 0.27 pg/g: CLAM 1A and 2A (Hart Crowser 2010) with values of 0.36 and 0.37 pg/g, respectively.

9.2.2 Geoduck Tissues

- Cadmium and mercury concentrations from Port Gamble geoduck tissues did not exceed natural background concentrations. The maximum concentrations for cadmium (0.19 mg/kg) and mercury (0.01 mg/kg) in Port Gamble geoduck tissues were at or below the median concentrations in natural background geoduck tissues.

- The median concentration of copper in Port Gamble geoduck tissues (3.1 mg/kg) was not significantly greater than natural background (2.1 mg/kg, $p \geq 0.05$), nor was the upper tail. The maximum copper concentration in Port Gamble was 3.3 mg/kg (GD Station 1A), identical to the maximum in natural background tissues.
- Carcinogenic PAH TEQs from all three of the Port Gamble geoduck tissues exceeded all of the natural background tissue TEQs (Mann-Whitney and Quantile test $p < 0.05$). The Port Gamble TEQs were 3.4 and 3.5 µg/kg, while the cPAH TEQs in natural background tissues ranged from 0.07 to 0.17 µg/kg.
- Dioxin/furan TEQs from the two Port Gamble geoduck tissues exceeded all of the TEQs in natural background tissues except one (TEQ = 1.4 ng/kg at RF06TG, a natural background station near Port Angeles). The medians and upper tails of the Port Gamble and natural background distributions were not statistically different ($p > 0.05$). The median and maximum dioxin/furan TEQs in Port Gamble geoduck tissues were 0.34 and 0.35 ng/kg, respectively, compared to 0.24 and 1.4 ng/kg in natural background tissues.
- There were no data available for arsenic or PCBs in geoduck tissues from natural background locations to which the Port Gamble tissues could be compared.

9.2.3 Crab Muscle Tissues

- Inorganic arsenic and mercury concentrations in Port Gamble crab muscle tissues did not exceed natural background. The maximum arsenic and mercury concentrations in Port Gamble tissues were 0.014 and 0.047 mg/kg, respectively, which were below the median natural background tissue concentrations of 0.020 and 0.051 mg/kg.
- Cadmium was detected in only one Port Gamble crab muscle tissue (0.04 mg/kg in CRAB1-A, Hart Crowser 2010). The detected concentration and the MRL for the non-detected Port Gamble tissues exceeded all the natural background concentrations (the maximum natural background concentration was 0.013 mg/kg). The Gehan test on medians was not statistically significant ($p > 0.05$); however, it was a low power test because of the small sample sizes and few detections.
- The median concentration of copper in Port Gamble crab muscle tissues (5.7 mg/kg) was not significantly greater than natural background (4.0 mg/kg, $p > 0.05$), but the upper tail of the distribution was significantly greater than natural background ($p < 0.05$). There were two crab muscle tissue samples with copper concentrations exceeding the maximum natural background concentration of 5.1 mg/kg: 5.7 and 8.7 mg/kg in PG11-BW-04-DCM-R1 (NewFields 2011) and CRAB1-A (Hart Crowser 2010), respectively.
- Carcinogenic PAH TEQs from the two Port Gamble composite crab muscle tissue samples collected in 2011 (0.35 and 0.35 µg/kg) were within the range of the natural background TEQs (0.11–1.6 µg/kg). The Port Gamble tissue sample collected in 2008 was higher, with a concentration of 3.5 µg/kg. The comparison of medians test indicated no difference (Mann-Whitney $p > 0.05$), but the Quantile test comparing the upper tails of the distributions indicated that the higher Port Gamble Bay sample was significantly elevated above natural background ($p < 0.05$).

- Data for total PCBs in crab muscle tissue were insufficient to make an adequate comparison to natural background. There were 17 natural background tissue samples with total PCBs ranging from 0.44 to 1.9 µg/kg, whereas the single Port Gamble crab muscle sample had a total PCB value reported as undetected at 8 U µg/kg.
- Dioxin/furan TEQs from Port Gamble crab muscle tissues were within the range of the natural background TEQs. Neither the median concentrations nor the upper tails of the distributions were statistically different ($p > 0.05$). The Port Gamble values ranged from 0.083 to 0.37 ng/kg, while the natural background values ranged from 0.027 to 0.38 ng/kg, in addition to two samples with elevated TEQs: 1.2 ng/kg in crabs collected near Hat Island and 1.4 ng/kg in crabs collected off Samish Island. Because not all of these TEQs were calculated in the same manner and detection limits varied significantly, these conclusions are not definitive and were not relied on for decision making.

9.2.4 Crab Hepatopancreas Tissues

- Inorganic arsenic, cadmium, copper, and mercury concentrations in Port Gamble crab hepatopancreas tissue samples were all well below natural background. The maximum concentrations among Port Gamble tissues were less than or comparable to the median concentrations in natural background crab hepatopancreas tissues.
- Carcinogenic PAH TEQs from the two Port Gamble composite crab hepatopancreas tissue samples collected in 2011 (0.35 and 0.35 µg/kg) were within the range of natural background TEQs (0.11–0.90 µg/kg). The Port Gamble tissue sample collected in 2008 was higher, with a concentration of 3.4 µg/kg. Both the median and upper tail of the Port Gamble distribution was significantly elevated relative to natural background ($p < 0.05$).
- Total PCBs in crab hepatopancreas tissue had insufficient data to adequately make a comparison to natural background. There were 15 natural background tissue samples with detected total PCB concentrations ranging from 8.8 to 50 µg/kg with a mean of 21 µg/kg. The single Port Gamble crab hepatopancreas sample had a total PCBs value reported as undetected at 20 U µg/kg. These data are limited, but they do not appear to indicate that total PCBs are elevated relative to natural background in crab hepatopancreas tissues.
- Dioxin/furan TEQs from Port Gamble crab hepatopancreas tissues had a median concentration (1.5 ng/kg) that was significantly elevated relative to natural background (0.52 ng/kg, $p < 0.05$). However, the upper tails of the two distributions overlapped and were not significantly different (Quantile test $p > 0.05$). The maximum TEQ for Port Gamble tissues was 2.2 ng/kg, less than the maximum of 2.6 ng/kg among natural background tissues (reported for sample 110111L from Skagit Bay), although detection limits were likely higher for the latter sample (PSEP 1991a).

Table 9-5. Comparison of Concentrations in Port Gamble Bay Tissues to Puget Sound Natural Background Tissues

Tissue Type	Endpoint	Test		p-value	Conclusion
Clams	**Arsenic**	Gehan		1.00	Site ≤ background
	Cadmium	Gehan Quantile		2E-04	Site > background Site > background
	Copper	No background data			
	Mercury	Gehan Quantile		0.47	Site ≤ background Site ≤ background
	Dioxin TEQ KM+Half	M-W		0.931	Site ≤ background
	PAH TEQ KM+Half	M-W Quantile		0.431	Site ≤ background Site > background
	PCB TEQ KM+Half		No background data		
	Total PCBs (Sum of Aroclors; U = 0 or MaxDL)	Gehan		0.39	Site ≤ background
Geoduck	**Arsenic**		No background data		
	Cadmium	M-W		0.80	Site ≤ background
	Copper	M-W Quantile		0.072	Site ≤ background Site ≤ background
	Mercury	Gehan		0.93	Site ≤ background
	Dioxin TEQ KM+Half	M-W Quantile		0.094	Site ≤ background Site ≤ background
	PAH TEQ KM+Half	M-W Quantile		0.029	Site > background Site > background
	PCB TEQ KM+Half		No background data		
	Total PCBs Sum of Aroclors (U=0 or Max DL)		No background data		
Oyster			No background data		
Crab - Muscle	**Arsenic**	M-W		0.964	Site ≤ background
	Cadmium	Gehan		0.155	Site ≤ background
	Copper	M-W Quantile		0.183	Site ≤ background Site > background

Table 9-5. Comparison of Concentrations in Port Gamble Bay Tissues to Puget Sound Natural Background Tissues

Tissue Type	Endpoint	Test	p-value	Conclusion
	Mercury	M-W	0.937	Site ≤ background
	Dioxin TEQ	M-W	0.184	Site ≤ background
	KM+Half	Quantile		Site ≤ background
	PAH TEQ	M-W	0.0629	Site ≤ background
	KM+Half	Quantile		Site > background
	PCB TEQ KM+Half	No background data		
	Total PCBs	Insufficient data for test (n = 1 in bay; 17 in background). The site value (8U) was greater than the maximum background value (1.9).		
Crab - Hepatopancreas	**Arsenic**	M-W	0.989	Site ≤ background
	Cadmium	M-W	0.974	Site ≤ background
	Copper	M-W	0.953	Site ≤ background
	Mercury	M-W	0.993	Site ≤ background
	Dioxin TEQ	M-W	0.0173	Site > background
	KM+Half	Quantile		Site ≤ background
	PAH TEQ	M-W	0.0341	Site > background
	KM+Half	Quantile		Site > background
	PCB TEQ KM+Half	No background data		
	Total PCBs	Insufficient data for test (n = 1 in bay; 15 in background). The site value (20U) was close to the mean of the background values (21).		

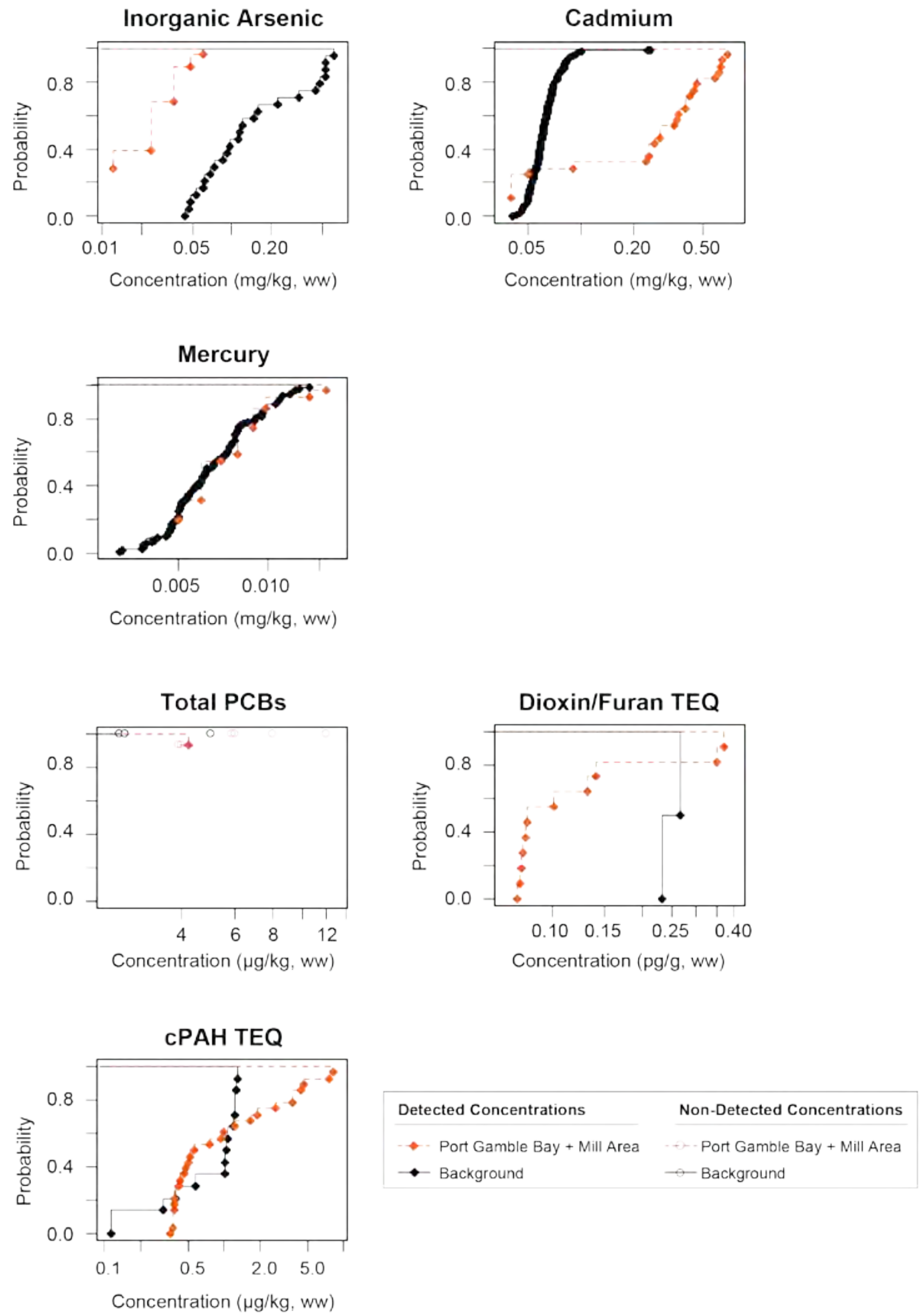

Figure 9-2. Empirical cumulative distribution plots for clam tissues

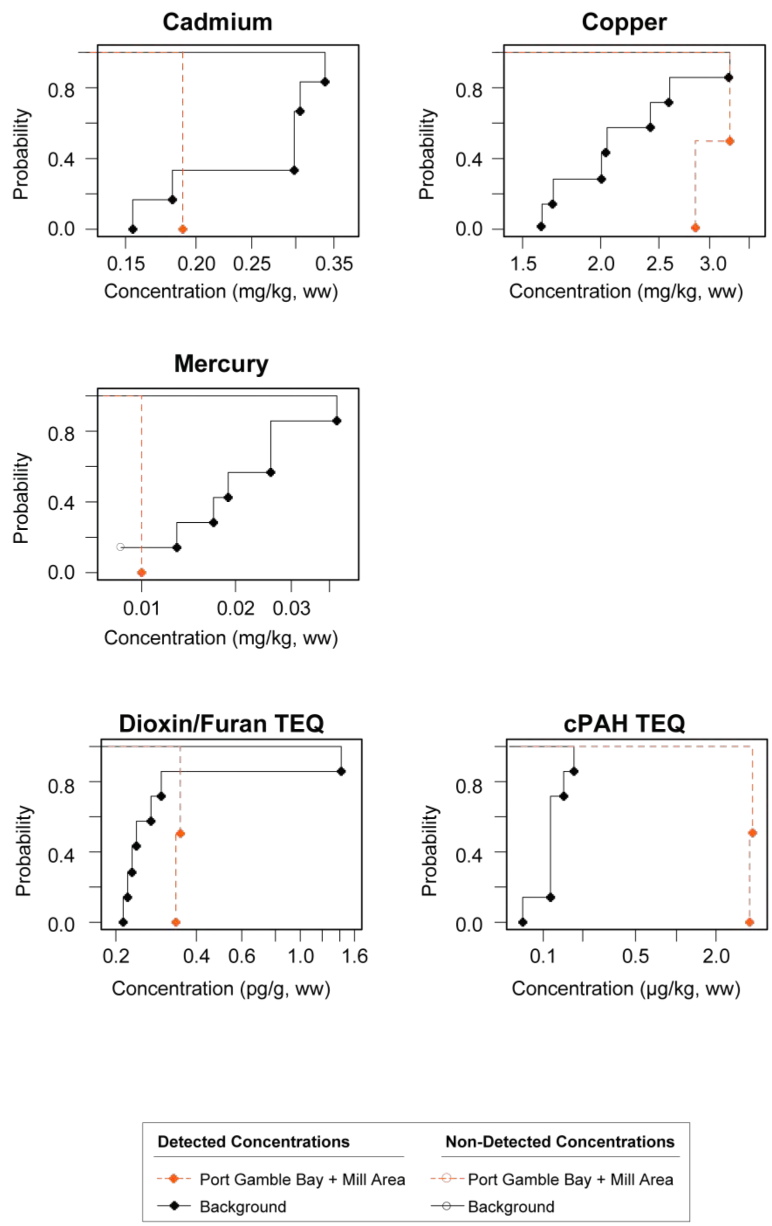

Figure 9-3. Empirical cumulative distribution plots for geoduck tissues

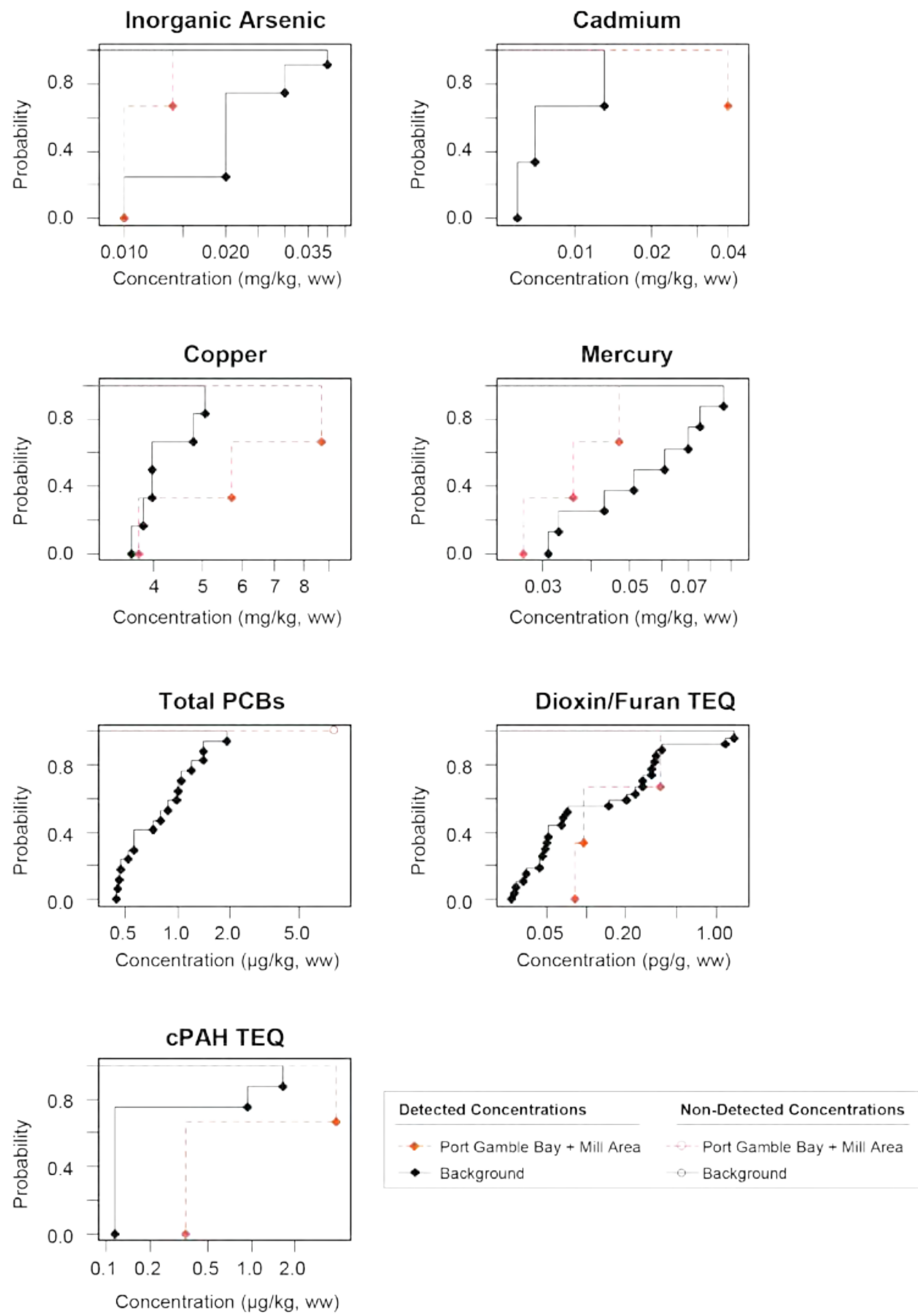

Figure 9-4. Empirical cumulative distribution plots for clam muscle tissues

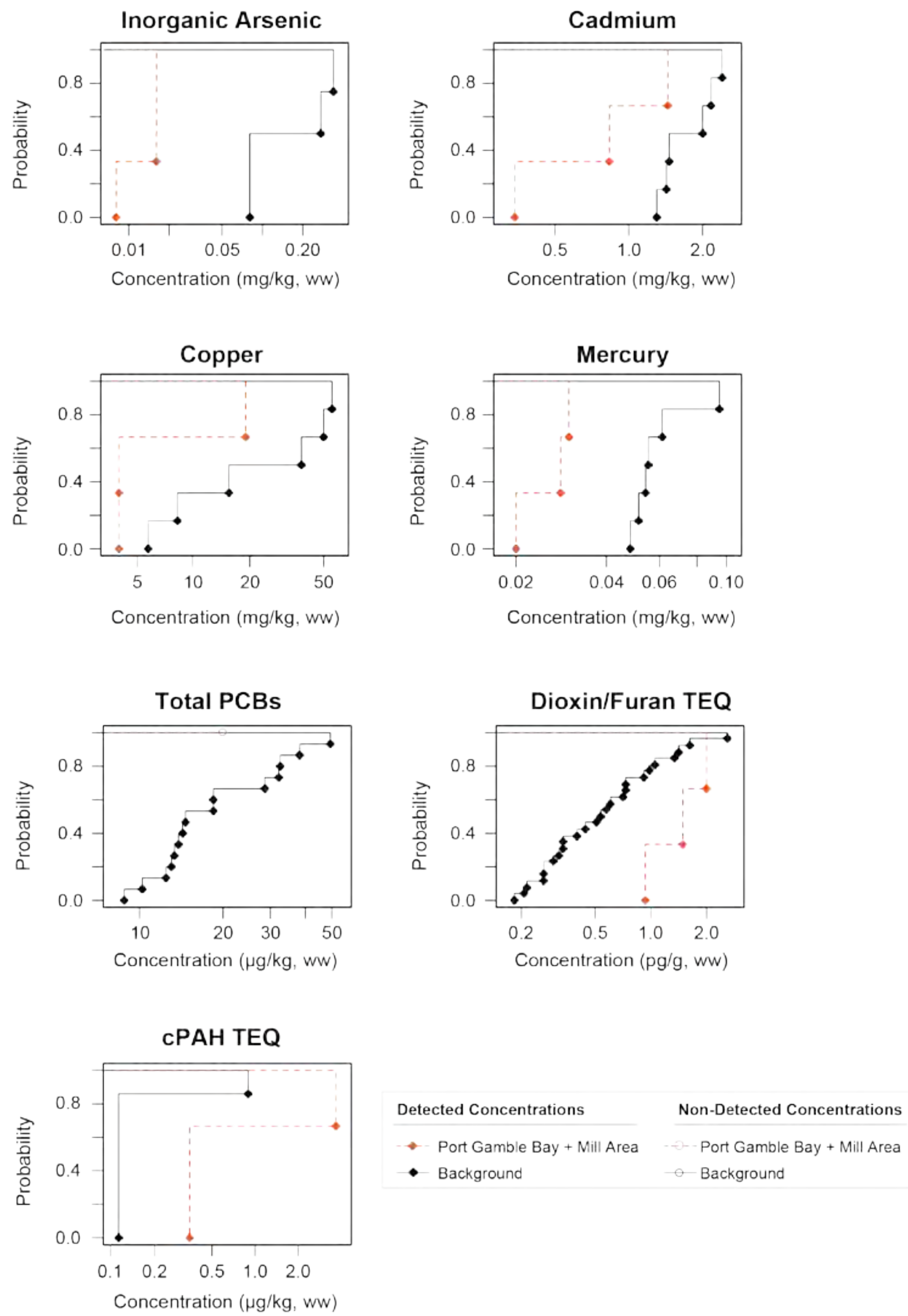

Figure 9-5. Empirical cumulative distribution plots for crab hepatopancreas tissues

9.3 Summary of Natural Background Comparisons for Sediments and Tissues

- **Arsenic.** The arsenic concentrations in the subtidal sediments of Port Gamble are comparable to natural background, and the intertidal sediment concentrations are well below natural background. Puget Sound natural background tissue data for arsenic were only available for clams and crabs; for these tissue types, Port Gamble inorganic arsenic concentrations were below Puget Sound natural background concentrations.
- **Cadmium.** The distribution of cadmium concentrations in Port Gamble Bay subtidal sediments was significantly elevated relative to Puget Sound natural background sediments. Cadmium in clam tissues was also significantly elevated relative to natural background concentrations. Only one of the three crab muscle tissue samples had a detected cadmium concentration, though this concentration exceeded all natural background values. Cadmium concentrations in crab hepatopancreas and geoduck tissues, as well as in intertidal sediments, were all below Puget Sound natural background concentrations.
- **Copper.** The distribution of copper in Port Gamble Bay subtidal sediments was comparable to natural background concentrations. The upper percentile of copper from Port Gamble crab muscle tissues exceeded natural background and both the upper percentile and the median Port Gamble concentration in geoduck exceeded natural background. Crab hepatopancreas tissue concentrations from Port Gamble were well below natural background.
- **Mercury.** The distributions of mercury in Port Gamble Bay subtidal sediments and tissues were comparable to Puget Sound natural background distributions.
- **cPAHs.** The median cPAH TEQ value found in Port Gamble Bay subtidal sediments was an order of magnitude above the natural background median sediment concentration. The upper percentile of cPAH TEQ values in Port Gamble tissues exceeded natural background for every tissue type, and median concentrations in Port Gamble Bay exceeded natural background for crab hepatopancreas and geoduck tissues. However, the upper percentile elevations calculated were based on non-detected concentrations in samples with elevated RLs.
- **Dioxins/Furans.** Concentrations of dioxin/furan TEQs in sediment of Port Gamble Bay were statistically elevated above natural background near the mill and in areas of the bay. Both the median and upper percentile sediment concentrations were significantly greater than natural background. The median dioxin/furan TEQ in crab hepatopancreas tissues from Port Gamble was significantly greater than in natural background tissues. Limited background data for other tissue types do not allow definitive conclusions at this time. Additional background data are expected to be gathered in upcoming sampling events that can be used for future monitoring events at Port Gamble.
- **PCBs.** Concentrations of PCBs in Port Gamble Bay sediments were generally within natural background ranges, with the exception of two intertidal sediment samples with elevated PCB TEQs (0.19 ng/kg and 0.24 ng/kg), which exceeded the maximum natural background TEQ by a factor of two. PCB Aroclors were largely undetected in Port Gamble sediments; site values are comparable to natural background ranges with the exception of one subtidal sample with elevated total PCBs (158 µg/kg). Total PCBs in tissues from Port Gamble were also largely undetected.

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10.0 CONCEPTUAL SITE MODEL

Based on all of the information presented above, the following conceptual site model has been developed for Port Gamble Bay:

10.1 Current and Former Sources

The following have been identified as likely contributors to contamination observed in Port Gamble Bay. While other potential sources exist (see Section 2), no other sources were identified despite additional sampling targeted at those potential areas.

- **Wood Waste.** Deposition of wood waste through log rafting, log transfer activities, chip loading, and other sources related to the former mill has resulted in thick deposits of wood chips, bark, and other debris both north and south of the mill site. Smaller amounts of wood debris can be seen at the FLA and at various locations along the shoreline. In turn, these wood waste deposits generate a variety of breakdown products, including toxic chemicals, resulting in elevated levels of TOC, TVS, sulfides, ammonia, resin acids, and phenols in sediments.
- **Creosoted Pilings.** Thousands of creosoted pilings and overwater structures are present near the former mill site and in areas to the south, with varying degrees of structural integrity. These pilings and structures continue to present an ongoing source of carcinogenic PAHs, other chemicals, and wood debris to the aquatic environment.
- **Wood Burning and Hog Fuel Boiler.** Historic burning of large quantities of wood debris at the mill, originally on an uncontained slab and later in a hog fuel boiler, released large but unknown amounts of particulate matter into the air. The prevailing winds indicate that much of this material would have settled out on the surrounding soils and in Port Gamble Bay, ultimately settling out into bottom sediments in the finer-grained areas of the bay. Ash was also generated by these wood-burning activities, which may have been deposited in the landfills or in other nearby upland areas. The particulates and ash would have contained PAHs, dioxins/furans, and potentially metals.
- **Upland Mill Activities.** Other historic industrial activities at the mill may have contributed to scattered exceedances of metals and PCB criteria along the southern and southwestern shoreline of the former mill.
- **Shoreline Debris.** Substantial shoreline debris is present at the former mill site and south along the shoreline in the landfill areas and continuing south to the FLTF and FLA areas. The debris varies from asphalted and creosoted materials to bricks, batteries, plastics, other landfill waste, and untreated wood. These materials may have contributed to some elevations observed (especially for metals) in coarser-grained areas where higher concentrations would not otherwise be expected.

10.2 Transport Pathways

The following contaminant transport pathways to human and ecological receptors formerly and/or currently exist at the site:

- **Currents and Tidal Fluctuations.** As wood deposits continue to break down near the mill through biological and chemical action, finer-grained organic matter is produced, which appears to be transported through currents and tidal action to the south-central areas of the bay and deposited there. All of the same wood waste breakdown products observed near the mill are found in this south-central portion of the bay, along with microscopic wood particles in the sediments.
- **Concentration of Clay Particles.** Similar processes concentrate very fine-grained natural sediments such as clays in the south end of the bay. Metals efficiently bind to clay particles and were found to be highly correlated with the percentage of clay in the sediments. Consistent with the patterns in metals concentrations observed, it appears that nearly all of the metals evaluated are naturally concentrated at the south end of the bay due to deposition of clay particles there. Cadmium levels in the very southeast corner of the bay exceed levels of concern through these natural processes.
- **Aerial Deposition.** Particulates from the wood burning activities at the former mill site would have been transported with the prevailing winds and deposited onto the surface of Port Gamble Bay, where currents and tidal fluctuations would have eventually deposited these particulates in the finer-grained south-central areas of the bay.
- **Stormwater Runoff.** Stormwater runoff of contaminants from the former mill site may have occurred during and after its operation. Based on the limited contamination observed of typical upland contaminants (e.g., metals, PCBs), this transport pathway likely affected mainly scattered intertidal sediments immediately adjacent to the site, primarily to the south and southwest of the former mill.

10.3 Ecological and Human Health Impacts

- **Benthic Effects.** Potential effects to benthic organisms have been evaluated through a variety of bioassay tests over 10 years of studies. Areas to the north and south of the former mill site consistently exceed larval bioassay biological criteria, and in some studies have exceeded amphipod and juvenile polychaete criteria as well. Smaller areas in the FLA and in the south-central portion of the bay also exceed larval bioassay biological criteria. The larval bioassay appears to be the test that is most sensitive to wood waste breakdown products and is of considerable concern due to the importance of shellfish reproduction in the bay.
- **Human Health Risks.** Several chemicals, including arsenic, cadmium, cPAHs, PCB congeners, and dioxin/furan congeners have predicted human health risks from seafood consumption that exceed MTCA/SMS risk levels, both in Port Gamble Bay and in natural background areas of Puget Sound. Of these, cadmium and cPAHs exceed Puget Sound natural background concentrations, and dioxin/furan concentrations exceed natural background concentrations over limited areas near the mill site and offshore of the FLTF.

11.0 CONTAMINANTS OF CONCERN AND CLEANUP STANDARDS

11.1 Contaminants of Concern

CoCs for ecological risk can generally be defined as wood waste breakdown products that are toxic to benthic organisms. Many of these chemicals do not have specific chemical criteria; however, they are composed of some combination of TOC, TVS, sulfides, ammonia, resin acids, and phenols, which were generally colocated with bioassay exceedances, as were areas of known wood waste deposits.

To be considered a site-related human health contaminant of concern, a chemical must meet several criteria:

- **Consistent with Conceptual Site Model.** The contaminant must be associated with known or suspected sources and pathways at the site. This first criterion is important to consider to avoid inclusion of contaminants that are present solely due to globally distributed transport pathways.
- **Human Health Risk.** The contaminant must be associated with a chemical-specific hazard index >1 or cancer risk $>10^{-6}$ for all exposure pathways combined.
- **Above Natural Background.** The contaminant must have elevated concentrations in site sediments above natural background concentrations in Puget Sound sediments. Comparison of site concentrations in tissue to natural background concentrations in tissue is an important secondary consideration; however, concentrations in tissues may have other sources and there are frequently fewer samples for comparison than in sediments.

Each chemical evaluated for human health risk is discussed according to these criteria below:

- **Arsenic.** There is no known pathway from the upland site despite intensive testing of soil and groundwater transport pathways and no other known sources around the bay. Arsenic appears to be present at the site due to naturally occurring geologic sources. Concentrations in sediments and tissues are lower than natural background concentrations. **Conclusion:** Arsenic is not a site-related CoC for human health.
- **Cadmium.** Cadmium may be associated with fly ash from wood-waste hog fuel burners, although there is no specific data indicating this. Cadmium is consistently but slightly elevated in sediments of the south-central part of the bay and is also elevated in some tissues (particularly clams) above natural background. It has a relatively low noncarcinogenic hazard quotient of approximately 3. **Conclusion:** Cadmium is a low-level CoC for human health.
- **Copper.** There are no known sources of copper at the site. The hazard quotient associated with copper is approximately 1. Copper is not elevated in sediments or tissues at the site compared to natural background except in geoducks. **Conclusion:** Copper is not a CoC for human health.
- **Mercury.** Mercury was removed from upland soils but was not observed at elevated levels in sediments adjacent to the mill or elsewhere in the bay. The hazard quotient associated with mercury is <1. Mercury is not elevated in sediments or tissues at the site compared to natural background. **Conclusion:** Mercury is not a CoC for human health.

- **Carcinogenic PAHs.** There are known sources of PAHs at the site, and carcinogenic risks are in the 10^{-4} range. Carcinogenic PAHs are elevated in both sediments and tissues compared to natural background. **Conclusion:** cPAHs are a primary site-related CoC for human health.
- **PCBs.** While there were isolated sources of PCBs on the upland mill site, there are no documented transport pathways to sediments and no other known sources of PCBs to the bay. PCBs are associated with risks of approximately $1x10^{-4}$; however, nearly all sediment and tissue samples are non-detects, so the calculated risks are based on detection limits. Two intertidal sediment concentrations exceeded natural background by a factor of 2 and will be included in active cleanup areas. No other tissues or sediments were above natural background concentrations/detection limits. **Conclusion:** PCBs are not a site-related CoC for human health.
- **Dioxins/Furans.** There was a known source of dioxins/furans at the former mill. Dioxins/furans at the site are associated with carcinogenic risks in the 10^{-4} range, and they are elevated in limited areas of sediments near the mill and offshore of the FLTF compared to natural background concentrations. Data for dioxins/furans in tissues in background areas are currently limited and largely undetected and, therefore, it is difficult to draw definitive conclusions with respect to background. **Conclusion:** Dioxins/furans are a site-related CoC for human health in specific areas of sediments. Future monitoring using a more robust and recent background tissue data set will allow clearer conclusions to be drawn regarding concentrations in tissues.

11.2 Ecological Risk-Based Cleanup Standards

As noted above, many of the wood waste breakdown products that are toxic to benthic organisms do not have numeric chemical criteria. In addition, a full suite of bioassay test results is available for nearly every station sampled near the mill and in Port Gamble Bay. Therefore, the SMS biological criteria will be used to delineate SMAs and as cleanup standards for ecological risk. Ecology has selected the SQS as the site-specific ecological cleanup standard for this site (see Section 7.5 and Figure 7-2 for stations that exceed the SQS).

11.3 Human Health Risk-Based Cleanup Standards

The cleanup standard for human health is defined as the highest of 1) risk-based concentrations, 2) natural background concentrations, and 3) practical quantitation limits (PQLs). Cleanup standards for cPAHs, cadmium, and dioxins/furans in sediment are based on the assumption that chemical concentrations in sediments are solely responsible for the chemical concentrations found in shellfish tissues in Port Gamble Bay.

Background threshold values (BTVs) were developed as one component of developing cleanup standards for human health and to identify individual site stations that are clearly different from background. BTVs were calculated as a 90/90 upper tolerance limit (UTL). A UTL is an upper confidence bound on a percentile, e.g., a 90/90 UTL is a 90% confidence bound on the 90^{th} percentile, indicating that 90% of the underlying background distribution is expected to be below this threshold with 90% confidence. This threshold was selected by Ecology to avoid including areas representative of natural background as cleanup areas, and to be consistent with other sediment management programs in Puget Sound.

ProUCL was used to evaluate the characteristics of the background data distribution, and the best-fit distributions based on goodness of fit tests and probability plots were selected. Background summary statistics and the BTVs are presented in Table 11-1.

Table 11-1. Derivation of Background Threshold Values (BTVs)

CoPC	Distribution	Method[1]	Mean[2]	SD[2]	50th percentile	90th percentile	BTV (90/90 UTL)
cPAH TEQ (µg/kg)	Lognormal	MLE	1.3	0.77	3.6	9.6	16
Cadmium (mg/kg)	Lognormal	MLE	-1.2	1.2	0.39	0.99	3.0
Dioxin/furan TEQ (ng/kg)	Lognormal	MLE	1.31	1.19	0.97	2.71	4.35

[1]Method for estimating the population mean and standard deviation (SD): MLE = Maximum likelihood estimates.

[2]Mean and standard deviation (SD) are shown on log scale for lognormal distributions; on concentration scale for normal distributions.

The BTVs for cadmium and cPAH TEQs are above PQLs, and therefore, the BTVs are selected as the cleanup standards for these analytes. However, the BTV for dioxin/furan TEQs is below the PQL for most laboratories accredited to perform this analysis by Washington State. Two surveys of accredited laboratories in 2011 determined that the lowest PQL that could consistently be achieved by the majority of the laboratories without qualification for blank contamination was approximately 5 ng/kg (MFA 2011). The median PQL for all of the accredited laboratories was also approximately 5 ng/kg and the mean was 6 ng/kg (Hart Crowser 2011). Therefore, Ecology has selected 5 ng/kg as the cleanup standard for sediments at Port Gamble.

11.4 Summary of Cleanup Standards

In summary, the following cleanup standards will be applied:

- **Toxicity due to wood waste breakdown products:** SQS numeric biological standards described in WAC 173-204-320(3)
- **cPAH TEQ:** 16 µg/kg
- **Dioxin/furan TEQ:** 5 ng/kg
- **Cadmium:** 3.0 mg/kg

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12.0 SEDIMENT MANAGEMENT AREAS AND SITE BOUNDARIES

SMAs are defined below based on similar characteristics, such as contaminants present, biological toxicity, geographic contiguity, and hydrologic considerations.

The following SMAs have been defined for Port Gamble Bay (Figure 12-1):

- **Mill Site North.** This SMA encompasses the embayment to the northeast of the former mill, between the jetty and the point. Mill Site North is characterized by deep wood chip deposits, large numbers of creosoted pilings and structures, biological toxicity at SQS and CSL levels, and high concentrations of TOC, TVS, porewater sulfides, and carcinogenic PAHs.
- **Mill Site South.** This SMA extends south of the former mill to Station MS-10. This area is characterized by deep deposits of wood chips and bark and also contains significant numbers of pilings and overwater structures. Stations throughout this area consistently exceed SQS biological standards and also have high concentrations of TOC, TVS, porewater sulfides, and the highest levels of cPAHs in the bay. In addition, areas along the southern shoreline of the former mill have dioxin/furan levels exceeding the BTV.
- **Central Bay.** This SMA encompasses four stations with SQS biological exceedances in the south-central area of the bay that were colocated with elevated levels of TOC, TVS, sulfides, ammonia, and resin acids.
- **Former Lease Area.** This SMA includes a relatively small area in the FLA characterized by SQS bioassay failures and elevated TOC, ammonia, resin acids, and phenols.
- **Carcinogenic PAHs.** This large area encompasses all stations that exceed the BTV for cPAHs in the bay. It also includes a subtidal area offshore of the FLTF that slightly exceeds the BTV for dioxins/furans and one station to the southeast that exceeds the BTV for cadmium. This SMA surrounds and includes all the other SMAs, and thus also serves as the site boundary.

All areas that exceeded site-specific cleanup standards were included within an SMA. SMAs may be refined further in the FS, including subdividing and applying different cleanup alternatives to subareas of an SMA based on environmental benefit, technical feasibility, cost, integration with planned restoration alternatives, and other considerations.

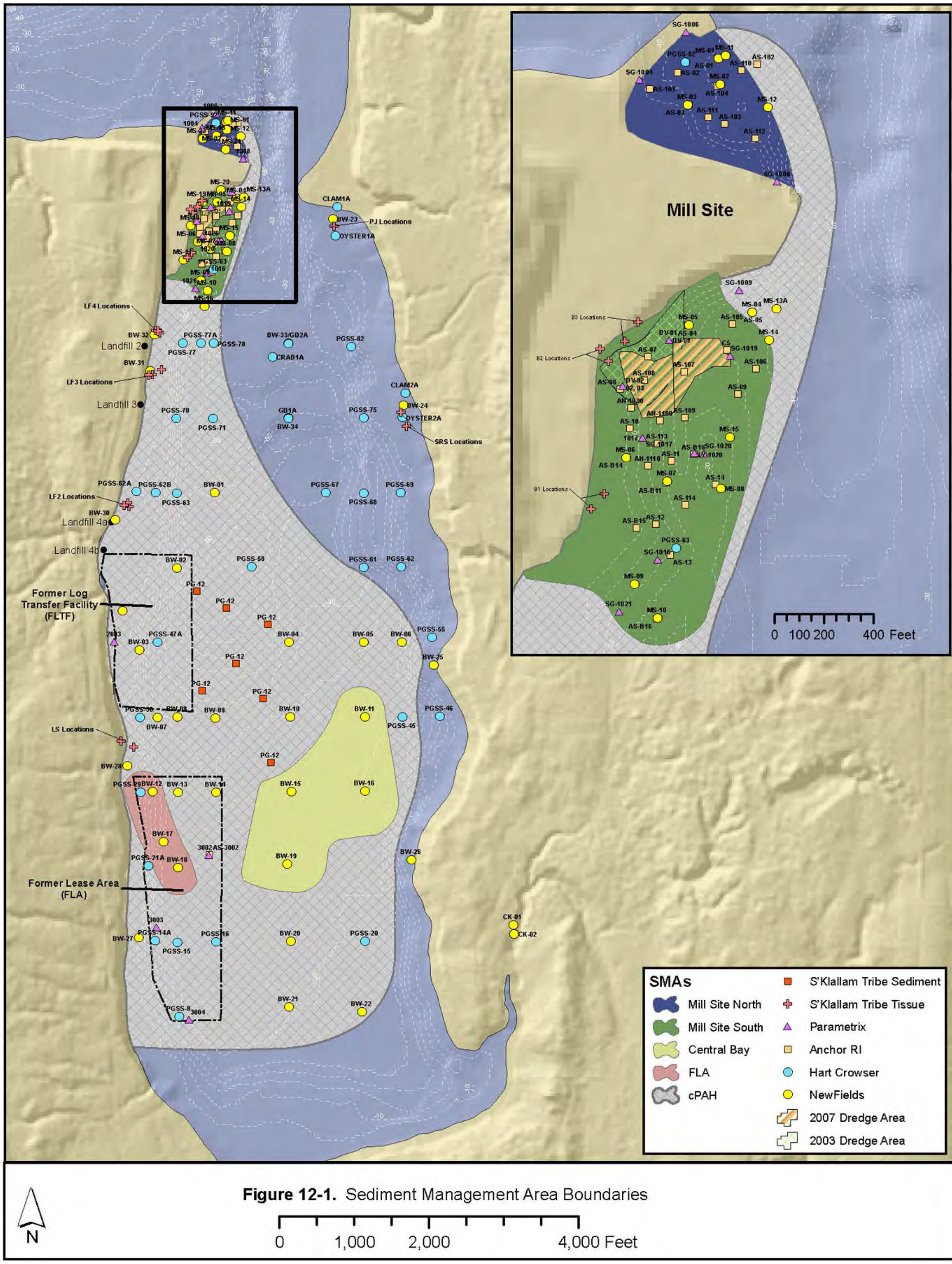

Figure 12-1. Sediment Management Area Boundaries

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APPENDIX A
SEDIMENT AND TISSUE DATA

APPENDIX B
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APPENDIX C
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APPENDIX D
REMEDIAL INVESTIGATION/FEASIBILITY STUDY
FORMER POPE & TALBOT INC., SAWMILL SITE, PORT GAMBLE, WASHINGTON

Feasibility Study
for
Port Gamble Bay

Port Gamble Bay and Mill Site
Port Gamble, WA

FINAL

Prepared by

DEPARTMENT OF
ECOLOGY
State of Washington

Toxics Cleanup Program
Aquatic Lands Cleanup Unit
Washington State Department of Ecology
Lacey, Washington

December 2012

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
µg/kg	micrograms per kilogram
AC	activated carbon
BMP	best management practice
BTV	background threshold value
CAP	Cleanup Action Plan
CFR	Code of Federal Regulations
cm	centimeters
cm/yr	centimeter per year
COC	contaminant of concern
Corps	U.S. Army Corps of Engineers
cPAH	carcinogenic polynuclear aromatic hydrocarbon
CQAP	Construction Quality Assurance Project Plan
CSL	Cleanup Screening Level
CSM	conceptual site model
CWA	Clean Water Act
cy	cubic yards
DAHP	Washington Department of Archaeology and Historic Preservation
DCA	MTCA Disproportionate Cost Analysis
DMMO	Dredged Material Management Office
DMMP	Dredged Material Management Program
DNR	Washington State Department of Natural Resources
Ecology	Washington State Department of Ecology
EMNR	enhanced, monitored natural recovery

EPA	U.S. Environmental Protection Agency
FLA	former lease area
FLTF	former log transfer facility
FS	feasibility study
g/day	grams per day
HPA	Hydraulic Project Approval
ng/kg	nanograms per kilogram
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MLLW	mean lower low water
MNR	monitored natural recovery
MTCA	Model Toxics Control Act
NHPA	National Historic Preservation Act
NWP	Nationwide Permit
OPG	Olympic Property Group
P&T	Pope & Talbot, Inc.
PCB	polychlorinated biphenyl
ppt	parts per thousand
PQL	practical quantitation limit
PR	Pope Resources LP
PSEP	Puget Sound Estuary Program
RCW	Revised Code of Washington
RI	remedial investigation
SEPA	State Environmental Policy Act
SMA	sediment management area
SMS	Sediment Management Standards

SPI	sediment profile imaging
SQS	Sediment Quality Standard
TEQ	toxicity equivalent quotient
TVS	total volatile solids
WAC	Washington Administrative Code
WSDOT	Washington State Department of Transportation

INTRODUCTION

This report presents a feasibility study (FS) assessment of cleanup options for sediments in Port Gamble Bay. This report is a companion to the remedial investigation (RI) report prepared by the Washington State Department of Ecology (Ecology). This FS has been prepared on behalf of Pope Resources LP (PR), the Washington State Department of Natural Resources (DNR), and Ecology. Under Ecology's Toxics Cleanup Program Puget Sound Initiative, Port Gamble Bay (Figure 1-1) is one of seven bays in Puget Sound identified for focused sediment cleanup and integrated habitat restoration actions, as appropriate. This FS evaluates a range of potential sediment remedial actions in Port Gamble Bay to restore and protect ecological receptors at the Site, consistent with current Washington State Model Toxics Control Act (MTCA; Chapter 173-340 Washington Administrative Code [WAC]) and Sediment Management Standards (SMS; Chapter 173-204 WAC) regulatory requirements.

Port Gamble Bay is located in Kitsap County and encompasses more than 2 square miles of subtidal and shallow intertidal habitat just south of the Strait of Juan de Fuca (Figure 1-1). Pope & Talbot, Inc. (P&T) continuously operated a sawmill facility at the mill site for a period of approximately 142 years (1853 to 1995). Over that period, the mill site underwent a variety of changes, including expansion by filling, as well as changes in the location and function of buildings and structures. A detailed history of the Site operations is presented in Parametrix (1999), and is summarized in Section 1.1. P&T leased the 72-acre portion of the former lease area (FLA) from DNR between 1970 to 2001 for log storage and transfer purposes (Parametrix 2002). Log rafting ceased in 1995 when the sawmill closed, and P&T removed pilings from the leased area in 1996. Similarly, log rafting and associated log sort yard activities that began in 1970 at the former log transfer facility (FLTF) ceased after P&T removed the pilings in 1996 (Parametrix 2003). Figure 1-1 also shows several historical landfills along the western shoreline, some of which received mill and municipal waste materials, but were subsequently remediated to MTCA standards.

As discussed in the RI report, chip loading, log rafting, and associated sawmill operations resulted in accumulations of wood waste on the bed of Port Gamble Bay, particularly at locations near the former sawmill facility.

The bay and surrounding areas support diverse aquatic and upland habitats, as well as resources for fishing, shellfish harvesting, and many other aquatic uses. The area surrounding the bay remains largely rural in nature, though more than 100 acres of the basin are currently in commercial land use, largely in the Gamble Creek watershed. The Port Gamble S'Klallam Tribal Reservation is located east of the bay, with extensive use of the bay by the tribe for shellfish harvesting, fishing, and other resources; an upland tribal casino operates in the watershed.

Site Background

In 1853, the corporate predecessor to P&T established one of the first sawmills on Puget Sound in Port Gamble. At that time, the mill site was a relatively small sand spit projecting east from the base of a bluff that forms the western boundary to the mouth of Port Gamble Bay. The Port Gamble Bay region is known to be archaeologically sensitive. At the time of contact with American settlers, the Port Gamble area was home to a S'Klallam Tribe village, which relocated to the Point Julia ("Little Boston") village site directly across the bay when operations began at the mill site in 1853. Four cultural resource areas have been identified along the shoreline of the mill site, and another four areas of potential historic significance have been identified along the western shoreline of the bay (NWAA 2010).

The mill operated as a forest products manufacturing facility from 1853 to 1995. The mill site underwent several changes over that period including filling activities, which expanded the upland area, moving building locations, and causing changes in functions of buildings and structures. Between 1853 and 1995, operations in Port Gamble included a succession of sawmill buildings, two chip loading facilities, a log transfer facility, and log rafting and storage areas. During the mill's operating period, logs were rafted and stored offshore of the mill site. In the late 1920s, a chip barge loading facility was installed on the north end of the mill site. During the mid-1970s, an additional chip barge loading facility (referred to as the alder mill) was constructed in the southeast portion of the sawmill property.

In 1985, P&T transferred ownership of the uplands and adjacent tidelands portion of the mill site to PR. P&T continued wood products manufacturing until 1995 under a lease with PR. Mill operations ceased in 1995, and the sawmill facility was dismantled and mostly removed in 1997. Since 1997, the uplands portion of the former sawmill facility has been leased to a variety of parties for use as a log sort and wood chipping yard, material handling activities, a marine laboratory, and parking for Washington State Department of Transportation (WSDOT) operations.

In January 1997, Ecology conducted an initial investigation of the former sawmill facility, which consisted of sampling sediment in four catch basins. The results of that investigation indicated that concentrations of petroleum hydrocarbons and metals were present at levels above MTCA and SMS chemical criteria for these compounds. Subsequently, Clean Services Company, Inc. removed accumulated materials from 12 catch basins, four valve vaults, and four sumps on April 23, 1997.

In July 1998, Ecology notified P&T of the potential listing of the former sawmill site on Ecology's Confirmed and Suspected Contaminated Site List. Subsequently, detailed environmental investigations were conducted by P&T and PR to characterize soil, groundwater, surface water, and sediment quality conditions at the Site (Parametrix 2000). The site characterization data confirmed the presence of hazardous substances in soil and groundwater in several mill site uplands areas. The investigations also confirmed the presence of wood waste in nearshore sediments. Based on these data, Ecology added the mill site to the hazardous sites list in 2001.

Between 2002 and 2005, approximately 26,310 tons of contaminated soils were excavated from the former sawmill facility uplands, and in 2003, approximately 13,500 cubic yards (cy) of sediment containing the greatest accumulations of wood waste was dredged from a 2-acre area in the bay. Both the upland soils and the 2003 wood waste dredge material were disposed of at approved upland facilities. In 2004, follow-on surface sediment sampling and sediment profile imaging (SPI) was conducted by P&T to characterize post-dredge sediment quality conditions and to provide a baseline dataset for evaluation of anticipated future natural recovery (Parametrix 2004). In 2006, P&T and Ecology performed additional sediment characterization, including benthic infaunal abundance, sediment bioassays, and SPI across a gradient of wood waste levels.

In early 2007, Ecology dredged an additional 17,500 in situ cy of wood waste in a 1-acre area adjacent to the 2003 dredging action and placed a 6-inch layer of clean sand over a portion of the newly dredged area. In cooperation with this Ecology-led project, P&T took over the day-to-day management of the dredged material once it was transferred from Port Gamble Bay and subsequently removed salt from the material utilizing an on-site upland holding cell and freshwater washing system to allow for upland beneficial reuse of these materials. Unsuitable solid waste materials were segregated and disposed of at an approved off-site landfill facility. All soil segregation, disposal, treatment, and relocation tasks were successfully completed in spring 2009, in accordance with Kitsap County Grading Permit 08-52323.

In November 2007, P&T filed for bankruptcy (Delaware Case No. 07-11738).

As discussed in the RI report, Ecology performed supplemental sediment and tissue sampling in Port Gamble Bay in 2011. This sampling was conducted in response to public comments on the draft bay-wide and Mill Site RI/FS reports, and included collection of additional sediment chemistry and sediment bioassay samples. During this time, the Port Gamble S'Klallam Tribe also collected sediment and tissue samples. The results of these additional investigations were combined with the data previously evaluated, and a revised bay-wide RI was prepared by Ecology reflecting these data and combining the Mill Site RI into a single comprehensive RI document.

Report Organization

The remainder of this FS is organized as follows:

- Section 2 summarizes the results of the RI, including a summary of the bay-wide environmental conditions, RI sampling, the conceptual site model (CSM), and the contaminants of concern (COCs) identified in the RI
- Section 3 describes the basis for the cleanup action, including a summary of cleanup standards and the locations requiring cleanup action evaluation as identified in the RI

- Section 4 describes the regulatory framework, including the objectives of the cleanup action, the applicable regulatory requirements, and screening of general response action technologies
- Section 5 describes the criteria used to evaluate the cleanup action alternatives
- Section 6 presents the development and evaluation of bay-wide sediment cleanup action alternatives
- Section 7 presents a summary of preferred bay-wide sediment cleanup actions
- Section 8 presents the references used in preparing this FS

The following appendix provides supporting technical evaluations for the FS:

- Appendix A – Detailed Cost Estimates

REMEDIAL INVESTIGATION SUMMARY

This section summarizes the findings of the RI report, including the nature and extent of sediment contamination, COCs, and cleanup standards, along with delineation of specific sediment management areas (SMAs) addressed in this FS.

Site Environmental Conditions

Port Gamble Bay is located in north-central Puget Sound in Kitsap County (Figure 1-1). The bay has water depths ranging from 0 to -65 feet mean lower low water (MLLW) datum, although more typical bottom elevations in the center of the bay range from -30 to -40 feet MLLW.

The bay is oriented with its long axis directed generally north to south, approximately 2.9 miles long and 0.9 miles wide at its maximum dimensions. Due to the long north/south fetch distance, wind-generated waves on the order of 1 to 3 feet are predicted in the bay for storms with recurrence intervals ranging from 50 to 100 years.

Table 2-1 summarizes tidal datum elevations within the bay, based on the MLLW vertical datum.

Table 2-1
Tidal Datum Information – Port Gamble Bay

Reference Plane	Elevation (feet)
Mean Higher High Water	10.3
Mean Tide Level	6.0
North American Vertical Datum of 1988 (NAVD88)	1.85
Mean Lower Low Water	0.0

Note: Based on National Oceanic and Atmospheric Administration Vertical Datum conversion at Latitude 47.85; Longitude -122.58

Summary of RI Sampling

Ten sampling investigations have been completed in Port Gamble Bay between 2000 and 2011. The results of these studies are described and incorporated in the RI report. Both sediment and tissue samples have been collected bay-wide, with additional focused sampling in the former sawmill area. The work has included surface sampling, sediment core collection, and SPI. In addition to sediment conventional data and chemistry, bioassay, and tissue sampling, work has also included radioisotope dating of sediment cores to characterize overall net sedimentation rates in the bay. Key conclusions from the sampling with respect to COCs are summarized in the sections below.

Conceptual Site Model

The CSM described in the RI report identified the following current and former sources of contamination to the bay: wood waste, creosoted pilings, wood burning and hog fuel boiler burning, upland mill activities, and shoreline debris.

The transport pathways identified in the CSM presented in the RI report include currents and tidal fluctuations, concentration of clay particles, aerial deposition, and stormwater runoff.

Potential ecological and human health risks were also identified in the CSM. Benthic effects have been studied primarily through a series of bioassay tests conducted during several studies over the last 10 years. The primary conclusion in the RI report is that risks to sensitive benthic invertebrates have been identified adjacent to portions of the former sawmill facility, in the FLA, and also in the south-central portion of the bay. Human health risks were also identified for those who may consume seafood obtained from both Port Gamble Bay and from natural background areas of Puget Sound. Overall concentrations of cadmium and dioxins/furans in Port Gamble Bay sediments were 2 to 3 times higher than Puget Sound natural background levels, and carcinogenic polynuclear aromatic hydrocarbon (cPAH) sediment concentrations were roughly 10 times higher in Port Gamble Bay compared to Puget Sound natural background levels.

Consistent with deposition rates measured throughout Puget Sound (Carpenter et al. 1985; Lavelle et al. 1985), net sedimentation rates throughout Port Gamble Bay average approximately 0.4 ± 0.1 centimeters per year (cm/yr), based on radioisotope dating (as described in the RI report), corrected for wood waste accumulations in the former mill site area (four cores total).

Contaminants of Concern

The RI report evaluated a series of human health COCs: metals (arsenic, cadmium, copper, and mercury), cPAHs, polychlorinated biphenyls (PCBs), and dioxins/furans. Of this list, cadmium, cPAHs, and dioxin/furans were identified as site-related human health COCs. Cadmium has been identified as a low-level COC for human health, while cPAHs have been identified as a primary COC for human health. Dioxins/furans are a site-related COC for human health in limited areas of Port Gamble Bay.

In addition, addressing biological toxicity observed in the RI will require cleaning up wood waste and its degradation byproducts associated with the observed RI bioassay failures, including wood waste (as measured by total volatile solids; TVS), phenols, resin acids, and total and dissolved sulfides.

BASIS FOR CLEANUP ACTION

This section summarizes the need for sediment cleanup actions within certain areas of Port Gamble Bay, hereinafter denoted as the "Site." There are two distinct elements that form the basis for the cleanup action: 1) site-specific cleanup standards; and 2) the locations and media requiring cleanup action evaluation. Each of these elements is described below.

Cleanup Standards

The RI report provides detailed discussions of cleanup standards for the Site, including both ecological risk-based and human health risk-based standards.

Ecological risk-based cleanup standards were based on SMS biological criteria, using the bioassay results presented in the RI report. The bioassay cleanup standard identified by Ecology for the Site is the Sediment Quality Standard (SQS) criterion, which was used to delineate SMAs as described subsequently in this section.

Human health risk-based standards were developed based on the highest of risk-based concentrations, natural background levels, and practical quantitation limits (PQLs). Standards were developed for cadmium, cPAHs, and dioxins/furans.

Sediment Cleanup Levels

Based on the evaluations described in the RI report, Table 3-1 summarizes the sediment cleanup levels that were identified by Ecology for the Site.

Table 3-1
Sediment Cleanup Levels

Chemical of Concern	Preliminary Cleanup Level
Toxicity due to wood waste breakdown products	SQS numeric biological standards described in WAC 172-204-320(3)
cPAH TEQ	16 μg/kg
Dioxin/furan TEQ	5 ng/kg
Cadmium	3.0 mg/kg

Points of Compliance

Under MTCA, the point of compliance is the point or location on a site where the cleanup levels must be attained. For marine sediments, the point of compliance for protection of the environment is surface sediments within the biologically active zone. The biologically active zone is not specified by rule, but represents the depth in surface sediments within which benthic organisms at the site are found. For most members of the benthic community, a 10-centimeter (cm) biologically active zone is considered appropriate (e.g., for benthic infauna such as polychaete worms). However, for geoducks, which are an important natural resource in Port Gamble Bay, the biologically active zone extends approximately 3 feet below the mudline (Straus et al. 2009).

The biologically active zone can include deeper sediments that could become exposed given conditions or Site uses that may be expected to occur following cleanup (e.g., storm events or propeller wash that contribute to erosional forces).

Locations Requiring Cleanup Action Evaluation

This section summarizes the RI report conclusions regarding locations at the Site that require cleanup action evaluation.

Based on RI evaluations, SMAs were delineated at the Site. Figure 3-1 presents the location of these SMAs. Briefly, the SMAs are as follows:

- **Mill Site North (SMA-1)**. An approximately 6-acre area located in the embayment north of the former sawmill facility. This SMA is characterized by localized deep deposits of wood debris near the former chip loading area, and was delineated based on bioassay results that exceed SQS criteria, elevated cPAH levels that exceed background, and elevated dioxins/furans that exceed background and the PQL.

- **Mill Site South (SMA-2)**. An approximately 19-acre area located immediately south and east, and adjacent to the former sawmill facility. This SMA is characterized by areas of relatively deep deposits of wood debris, particularly adjacent to the former alder mill chip loading area, and was delineated based on bioassay results that exceed SQS criteria, elevated cPAH levels that exceed background, and elevated dioxins/furans that exceed background and the PQL.
- **Former Lease Area (SMA-3)**. An approximately 19-acre area located along the western shoreline of the south-central portion of the bay. This area was delineated based on bioassay results that exceed SQS criteria and the presence of wood waste breakdown products in sediments.
- **Central Bay (SMA-4)**. An approximately 77-acre area located in the south-central portion of Port Gamble Bay. This area was delineated based on bioassay results that exceed SQS criteria and the presence of wood waste breakdown products in sediments.
- **cPAH Background Area (SMA-5)**. An approximately 602-acre area that encompasses all of the other SMAs and serves as the Site boundary. The boundary of this SMA was developed based on surface sediment cPAH that exceeds natural background levels. It also includes an area of elevated dioxins/furans near the FLA and one station at which cadmium exceeds natural background levels.

The SMAs presented in the RI report are used in this FS to define the horizontal extents for development and evaluation of cleanup action alternatives. Within a given SMA for a particular alternative, multiple response action technologies may be appropriate in various combinations depending on SMA-specific considerations. Details of the alternatives development and further discussion of horizontal and vertical extents are presented subsequently in this FS.

REGULATORY FRAMEWORK

This section presents cleanup action objectives, applicable regulatory requirements for the cleanup action, and a screening evaluation of general response actions and remediation technologies that are potentially applicable to the Site.

Cleanup Action Objectives

Cleanup action objectives consist of chemical- and medium-specific goals for protecting the environment. The cleanup action objectives specify the media and contaminants of interest, potential exposure routes and receptors, and proposed cleanup goals for bay-wide sediments.

The cleanup action objectives for this FS are focused on sediments and the COCs listed in Table 3-1, including:

- Toxicity due to wood waste breakdown products
- Carcinogenic petroleum hydrocarbons toxicity equivalent quotient (TEQ)
- Dioxin/furan TEQ
- Cadmium

Exposure routes addressed in this FS include transport pathways to benthic receptors and humans. Transport pathways described in the RI are: 1) currents and tidal fluctuations; 2) concentrations of clay particles; 3) aerial deposition; and 4) stormwater runoff. Exposure of benthos and humans results from both direct contact with and ingestion of sediments; in the case of human exposure, ingestion primarily occurs indirectly through shellfish consumption and secondarily through incidental ingestion of sediments during shellfish harvesting and other beach uses.

The sediment cleanup action objectives for this FS are summarized as follows:

1. Eliminate, reduce, or otherwise control to the extent practicable risks to benthic organisms through exposure to sediments or porewater containing deleterious wood waste and/or other chemicals that exceed the benthic chemical or biological criteria described in the RI.

2. Eliminate, reduce, or otherwise control to the extent practicable risks to humans from ingestion of seafood containing chemicals that exceed risk-based concentrations and/or natural background concentrations.

Applicable Regulatory Requirements

In addition to the cleanup standards developed through the SMS process, other regulatory requirements must be considered in the selection and implementation of a cleanup action. SMS and MTCA require cleanup standards to be at least as stringent as all applicable state and federal laws [WAC 173-340-700(6)(a)]. In addition to establishing minimum requirements for cleanup standards, applicable state and federal laws may also impose certain technical and procedural requirements for performing cleanup actions. These requirements are described in WAC 173-340-710. Applicable state and federal laws are discussed below.

While implementation plans are still under development, the cleanup action at the Site will likely be performed pursuant to SMS under the terms of a Consent Decree between Ecology and one or more implementing parties. Accordingly, the anticipated cleanup action will likely meet the permit exemption provisions of MTCA, obviating the need to follow procedural requirements of the various local and state regulations that would otherwise apply to the action. Similarly, the anticipated cleanup action also qualifies for a U.S. Army Corps of Engineers (Corps) Nationwide Permit 38 (NWP 38). Nevertheless, federal consultation under the Endangered Species Act, Section 401 Water Quality Certification, and other substantive requirements must still be met by the cleanup action. Ecology will be responsible for issuing the final approval for the cleanup action, following consultation with other state and local regulators. The Corps will separately be responsible for issuing approval of the project under NWP 38, following Endangered Species Act consultation with the federal Natural Resource Trustees, and also incorporating Ecology's 401 Water Quality Certification.

SMS and MTCA Requirements

The primary law that governs the cleanup of contaminated sites in the state of Washington is MTCA (WAC 173-340), with sediment cleanup sites primarily governed under the state SMS (WAC 173-204). The SMS were developed to establish cleanup standards for marine, low salinity, and freshwater environments for the purpose of reducing and/or eliminating adverse effects on biological resources and significant health threats to humans from surface sediment contamination. Both SMS and MTCA regulations require that cleanup actions must protect human health and the environment, meet environmental standards in other applicable laws, and provide for monitoring to confirm compliance with cleanup levels.

SMS requires that cleanup actions meet the threshold requirements of overall protection of human health and the environment and attainment of cleanup standards, with selection of an appropriate cleanup action considering the following additional factors: short-term effectiveness, long-term effectiveness, implementability, cost, community concerns, the use of recycling, reuse and waste minimization, and environmental impact (WAC 173-204-560). Ecology's recommended time frame for sediment cleanup actions to achieve the cleanup level under SMS is 10 years, as practicable (WAC 173-204-570). For those cases where the 10-year time frame cannot be practicably met, Ecology may authorize a cleanup time frame that exceeds 10 years, requiring a technical impracticability demonstration as part of the FS.

The key SMS decision-making document for cleanup actions is the RI/FS. In the RI/FS, the nature and extent of contamination and the associated risks at a site are evaluated, and potential alternatives for conducting a site cleanup action are identified. The cleanup action alternatives are then evaluated against SMS remedy selection criteria, and one or more preferred alternatives are selected. After reviewing the RI/FS, and after consideration of public comment, Ecology then selects a cleanup action for the site and documents the selection in a Cleanup Action Plan (CAP). Following public review of the CAP, the site cleanup process typically moves forward into design, permitting, construction, and long-term monitoring.

This FS report was prepared consistent with the requirements of the SMS and MTCA.

Solid and Hazardous Waste Management

The Washington Hazardous Waste Management Act (Revised Code of Washington [RCW] 70.105) and the implementing regulations, the Dangerous Waste Regulations (Chapter 173-303 WAC), would apply if dangerous wastes are generated during the cleanup action. There is no indication of dangerous wastes being generated or disposed of at the Site. Related regulations include state and federal requirements for solid waste handling and disposal facilities (40 Code of Federal Regulations [CFR] 241, 257; Chapter 173-350 and -351 WAC) and land disposal restrictions (40 CFR 268; WAC 173-303-340).

Puget Sound Dredged Material Management Program

In Puget Sound, the open-water disposal of sediments is managed under the Dredged Material Management Program (DMMP). This program is administered jointly by the Corps, the U.S. Environmental Protection Agency (EPA), DNR, and Ecology. The DMMP developed the Puget Sound Dredge Disposal Analysis protocols, which include testing requirements to characterize whether dredged sediments are appropriate for open-water disposal. The results of this characterization are formalized in a written suitability determination from the Dredged Material Management Office (DMMO).

The DMMP has also designated disposal sites throughout Puget Sound. Initial DMMP characterization of sediments has been performed on representative subsurface samples collected from the wood chip deposit in the Mill Site North SMA (including bioassay and dioxin testing), and these data indicated that wood waste material from this part of the Site is likely suitable for unconfined open-water disposal at a non-dispersive location (e.g., at the nearby Port Gardner disposal site). Similar wood waste materials have also been determined to be suitable for open-water disposal at DMMP facilities (e.g., DMMP 2009). However, if this option is selected, additional dredged material characterization would be required to complete the suitability determination. Use of DMMP facilities would need to comply with other DMMP requirements including material approval, disposal requirements, and payment of disposal site fees.

State Environmental Policy Act

The State Environmental Policy Act (SEPA) (RCW 43.21C; WAC 197-11) and the SEPA procedures (WAC 173-802) are intended to ensure that state and local government officials consider environmental values when making decisions. The SEPA process begins when an application for a permit is submitted to an agency, or an agency proposes to take some official action such as implementing a MTCA CAP. Prior to taking any action on a proposal, agencies must follow specific procedures to ensure that appropriate consideration has been given to the environment. The severity of potential environmental impacts associated with a project determines whether an Environmental Impact Statement is required. A SEPA checklist would be required prior to initiating remedial construction activities. Because the Site cleanup action will be performed under a Consent Decree, SEPA and MTCA requirements will be coordinated, if possible.

Shoreline Management Act

The Shoreline Management Act (RCW 90.58) and its implementing regulations establish requirements for substantial developments occurring within water areas of the state or within 200 feet of the shoreline. Local shoreline management master programs are adopted under state regulations, creating an enforceable state law. Because the Site cleanup action will likely be performed under a Consent Decree, compliance with substantive requirements would be necessary, but a shoreline permit would not likely be required.

Washington Hydraulics Code

The Washington Hydraulics Code (WAC 220-110) establishes regulations for the construction of any hydraulic project or the performance of any work that will use, divert, obstruct, or change the natural flow or bed of any of the salt or fresh water of the state. The code also creates a program requiring Hydraulic Project Approval (HPA) permits for any activities that could adversely affect fisheries and water resources. Timing restrictions and technical requirements under the hydraulics code are applicable to dredging, construction of sediment caps, and placement of post-dredge residual covers if necessary. For the reasons stated above, the procedural requirements of an HPA permit would not likely be required, though the substantive requirements of an HPA must still be met by the cleanup action.

The FS has been prepared using durations that recognize potential fish closure periods, during which time dredging and any in-water work will not be permitted. Exact in-water closure periods will be determined through agency and tribal consultation.

Water Management

Clean Water Act

The Clean Water Act (CWA) is the primary federal law for protecting water quality from pollution. The CWA regulations provide requirements for the discharge of dredged or fill material to waters of the United States and are applicable to any in-water work. The CWA regulations also prescribe permitting requirements for point source and non-point source discharges. Acute marine criteria are relevant and appropriate requirements for discharges to marine surface water during sediment dredging, as well as for return flows (if necessary) to surface waters from dewatering operations.

Section 404 of the CWA requires permits from the Corps for discharges of dredged or fill material into waters of the United States, including wetlands. Section 404 permits depend on suitability determinations (described previously) according to DMMP guidelines.

Section 404(b)(1) requires an alternatives analysis as part of the permitting process. Requirements for all known, available, and reasonable technologies for treating waste water prior to discharge to state waters are applicable to any dewatering of marine sediment prior to upland disposal. Section 401 of the CWA requires the state to certify that federal permits are consistent with water quality standards. The substantive requirements of a certification determination are applicable.

Ecology has promulgated statewide water quality standards under the Washington Water Pollution Control Act (RCW 90.48). Under these standards, all surface waters of the state are divided into classes (Extraordinary, Excellent, Good, and Fair) based on the aquatic life uses of the water bodies. Water quality criteria are defined for different types of pollutants and the characteristic uses for each class of surface water. The standards for marine waters will be applicable to discharges to surface water during sediment dredging, and return flows (if necessary) to surface waters from dewatering operations.

Construction Stormwater General Permit

Construction activities that disturb 1 acre or more of land need to comply with the provisions of construction stormwater regulations. Ecology has determined that a construction stormwater general permit is not covered under the permit exemption provisions of MTCA, and thus a project-specific construction stormwater permit would be required if land disturbance greater than 1 acre is necessary. It is anticipated that the construction stormwater general permit would be obtained during the design phase and a Construction Quality Assurance Project Plan (CQAP) would also be prepared as part of the remedial design process, supplemented as appropriate by the remedial contractor.

Other Applicable Regulatory Requirements

The following is a list of other applicable regulations for the cleanup action:

- **Archaeological and Historic Preservation** – The Archaeological and Historic Preservation Act (16 USCA 496a-1) will apply if any subject materials are discovered during Site grading and excavation activities. Previously conducted cultural resource surveys indicate several areas of significant historical interest in the bay. Prior to construction, a more detailed cultural resources survey will be conducted during remedial design and a monitoring and management plan prepared to ensure protection of archaeological and/or historic resources.

- **Health and Safety** – Site cleanup-related construction activities will be performed in accordance with the requirements of the Washington Industrial Safety and Health Act (RCW 49.17) and the federal Occupational Safety and Health Act (29 CFR 1910, 1926). These applicable regulations include requirements that workers are to be protected from exposure to contaminants and that excavations are to be properly shored.

These requirements are not specifically addressed in the detailed analysis of cleanup action alternatives because they apply to any active cleanup alternative.

Screening of General Response Actions

This section presents a screening evaluation of potentially applicable general response actions and remediation technologies for the cleanup action. Based on the screening evaluation, selected response actions and technologies are carried forward for use in the development of cleanup action alternatives.

No Action

The No Action alternative does not achieve the project objectives of protecting human health and the environment and, thus, has been screened from further evaluation for sediments.

Institutional Controls

For any aquatic construction project (e.g., dredging), environmental reviews are conducted by permitting agencies including the Corps, Ecology, and other resource agencies. These reviews include a review of area files relating to sediment conditions and requirements to address materials management and water quality.

Additional institutional controls may be implemented as appropriate, depending on the preferred cleanup action alternative. Such additional controls could include restrictive covenants for platted tidelands, use authorizations for state-owned aquatic lands, and/or documenting the Site cleanup action in Corps and regulatory agency permit records and records maintained by the State of Washington for state-owned aquatic lands.

Institutional controls can be effective, implementable, and cost-effective provided that the cleanup action for which the institutional controls are implemented is consistent with marine land and navigation uses. In cases where the proposed cleanup action is incompatible with land use and navigation uses, conflicts can result, which can jeopardize the effectiveness of institutional controls or require mitigation. While the use of institutional controls is not carried forward as an independent action for detailed evaluation, the use of institutional controls may be appropriate in combination with other general response actions, and thus would be considered as an additive requirement where appropriate.

Source Control

Wood waste source controls within the Port Gamble Bay area were implemented during and following mill operations. Discontinuation of hog fuel burning eliminated one primary source of dioxins/furans and cPAHs. Cleanup of upland areas of the site and landfills along the shoreline have further reduced sources related to the former mill. Additional source control for cPAHs will occur through removal of creosoted structures and pilings. All piling removal will also be sequenced with follow-on dredging or capping actions to maximize control of piling removal residuals. Piling removal and disposal will target complete removal using equipment preferences and best management practices (BMPs) identified in the statewide Hydraulic Project Approval (HPA) - *Creosote Piling and Structural Removal* (WDFW 2011) and the accompanying DNR Puget Sound Initiative – *Derelict Creosote Piling Removal, BMPs for Pile Removal and Disposal* (DNR 2011). Areas of extensive piling removal not otherwise anticipated to be later capped or dredged will be covered with 6 inches of sand to control anticipated piling removal residuals. This action is compatible with and supports all of the following technologies and will be part of the selected alternative for all SMAs in which creosoted pilings and structures are present.

Monitored Natural Recovery

Natural processes that are fundamental to the recovery of wood waste- or cPAH-impacted sediments following source control include sedimentation and biodegradation. The monitored natural recovery (MNR) remedy relies on these processes to reduce risks to acceptable levels following source control, while monitoring recovery over time to verify remedy success (Magar et al. 2009).

MNR lines of evidence can be developed from rigorous analyses of Site data (e.g., laboratory and field studies, modeling, and other activities) that define the role of natural processes in reducing risk. Key factors for determining whether MNR is an appropriate remedy include the ability to achieve and sustain an acceptable level of risk reduction through natural processes within an acceptable period of time. Predicting future natural recovery rates requires site-specific inputs to numerical models, such as the net sedimentation rate (which averages approximately 0.4 ± 0.1 cm/yr at the Site, as described above), to quantify processes described in the CSM and associated lines of evidence. Numerical models can be used to develop estimates of time to recovery using baseline data to determine likely effectiveness of MNR implementation.

Natural recovery processes operate regardless of the selected remedy. Effective sediment remedies may incorporate MNR in combination with approaches such as engineered containment or removal. Factors particularly favorable to MNR include evidence that natural recovery will effectively reduce risks within an acceptable time period, the ability to manage risks during the recovery period, and (where physical isolation is important) a low potential for exposure of buried contaminants. In SMAs where this technology is potentially promising, MNR was retained as a response action for more detailed evaluation in this FS.

Under SMS, preference is given to remedies providing for timely cleanup, taking into account potential risks posed by a site and practicability of achieving cleanup standards in less than a 10-year time frame. Where natural recovery time frames are expected to be greater than 10 years but there is no practicable cleanup alternative, a technical practicability evaluation is required in the FS.

Enhanced Monitored Natural Recovery

Enhanced monitored natural recovery (EMNR) involves active measures, such as the placement of a thin layer of suitable sand or sediment, to accelerate the natural recovery process. EMNR is often applied in areas where natural recovery may appear to be an appropriate remedy, yet the rate of sedimentation or other natural processes is insufficient to reduce potentially unacceptable risks within an acceptable timeframe (EPA 2005). The acceleration of natural recovery most often occurs due to burial and/or incorporation and mixing of the clean material into the contaminated surface sediments through bioturbation and physical mixing processes. Other recovery processes can also occur such as binding of contaminants to organic carbon in the clean material, particularly if the material is from a clean sediment source with naturally occurring organic carbon. Placement of such EMNR materials is typically different than capping (discussed in Section 4.3.6), because it is not designed to provide long-term isolation of contaminants. Clean sand or sediment can be placed in a relatively uniform thin layer over a contaminated area or it can be placed in berms or windrows, allowing natural sediment transport processes to distribute the clean material over wider areas. As with MNR, EMNR includes both monitoring and contingency plan components to verify that recovery is occurring as expected, and to respond accordingly.

EMNR can be highly effective where natural recovery is occurring, but at a slower rate than desired. In many areas of the Site, the most recent bioassay test results are close to achieving SQS biological criteria. EMNR in these locations is one strategy that can effectively improve surface sediment conditions upon application, and thus the expected recovery in these marginal exceedance areas should occur within the SMS 10-year timeframe, although achieving human health risk-based criteria may take longer. EMNR is also an effective strategy for managing dredge residuals, as discussed below. EMNR has been retained is a general response action for this FS, and would entail placement of a nominal 6-inch-thick layer of clean sediment.

EMNR sediment would be obtained from a clean marine beneficial reuse sediment source to ensure maximum compatibility with and the quickest recovery of the benthic community. A specific source for this material has not been identified for this FS. Prior project experience suggests that the availability of clean material from relatively local beneficial reuse projects changes over time, and thus the availability of sources would need to be more fully understood and evaluated during remedial design. If material is only available on a limited basis each year, this could extend the implementation timeline of those projects that require larger volumes of EMNR sediments.

Engineered Containment

Engineered containment for sediments involves placing a suitable cap to isolate contaminated material for protection of the biological receptors of interest (e.g., benthic infauna, forage fish, and geoduck in Port Gamble Bay) and human routes of exposure. In the aquatic environment, the containment must be designed to withstand erosive forces generated by wave action and propeller wash, and must be thick enough to provide the required isolation of the material contained by the cap. Monitoring results at other sites in the Puget Sound region have shown that containment can provide effective sediment remediation without the risks involved in removing contaminants by dredging (Sumeri 1996). Engineered containment was retained for further evaluation in this FS.

Placing a layer of cap material (12 or 48 inches thick, depending on location-specific biological requirements) can provide isolation of potentially contaminated sediments. Aggregate caps (e.g., with a gravel surface) may potentially be appropriate for consideration in sediment areas with high potential for disturbance (e.g., from propeller wash or wind-generated wave forces) or in intertidal zones where the natural habitat is coarse-grained.

If selected as part of the Site remedy, a sediment cap would be designed to effectively contain and isolate contaminated sediments from the biologically active surface zone in accordance with EPA and Corps cap design criteria (see below). The cap would be designed to be thick enough and of sufficient grain size to maintain its integrity under reasonable worst-case conditions.

Engineered caps at the Site would be designed to ensure that wood waste is effectively confined below the cap and that post-cap sediment porewater sulfide concentrations in the biologically active zone (0 to 10 cm for most receptors, and 0 to 3 feet specifically for geoducks) are maintained below the no effects threshold of 3.4 milligrams per liter (mg/L) cited by the DMMP for *Neanthes* testing (Kendall and Barton 2004).

Cap designs to maintain porewater sulfide exposure below these performance standards would be developed considering surface and subsurface sediment porewater concentrations measured during the RI/FS, and also considering groundwater upwelling, tidally induced transient porewater flow reversal, and geochemical processes at the Site. Tidal reversals can promote sulfide production in wood waste deposits by supplying sulfate-rich seawater to wood chips confined below the cap, and are most pronounced in the near-surface permeable soils of the shallow aquifer at the Site that are adjacent to intertidal and shallow subtidal areas of the Site. During the design phase, hydraulic and/or geochemical modeling may be necessary to assess potential groundwater discharge into a cap to confirm the protectiveness of the cap.

Sediment caps would be constructed of clean silt/sand and/or sand and gravel materials and could be placed by a number of mechanical and hydraulic methods. Cap material would either be provided from a beneficial reuse marine dredging project or from a commercial quarry in cases where beneficial reuse material would not provide the appropriate grain size. The grain size requirements would be determined during remedial design based on consideration of erosive forces (e.g., wind/wave, propeller wash) and habitat compatibility as discussed subsequently, and would likely vary depending on elevation and location.

Table 4-1 provides a general summary of protective cap designs in Puget Sound that have been developed and approved under both EPA and Ecology cleanup programs. Cap designs must meet stringent criteria set forth in EPA and Corps design guidance, including EPA (2005) and Palermo et al. (1998a, 1998b). These guidance documents provide detailed procedures for cap design, cap placement operations, and monitoring of engineered caps, and have been relied upon extensively for successful cap designs at other SMS cleanup sites. Caps designed according to the EPA and Corps guidance have been demonstrated to be protective of human health and the environment (EPA 2005). Design specifications for in situ engineered caps in Port Gamble would be further refined during remedial design based on detailed analyses of the following components:

- Bioturbation/habitat quality
- Habitat compatibility
- Erosion (e.g., propeller wash, tidal currents, waves, wakes, and slope stability)
- Chemical isolation (accounting for tidal advection of porewater/groundwater)
- Consolidation
- Operational considerations (e.g., gas generation and placement inaccuracies)

Table 4-1

Regional Sediment Capping Projects

Water Body	Project	Regulatory Program	Year	Contaminants of Concern	Cap Design(s)
Bellingham Bay	Georgia-Pacific Log Pond	MTCA	2001	Mercury, wood debris, phenols	3-foot-thick sand cap
Eagle Harbor	Eagle Harbor (East Harbor)	CERCLA	1994	PAHs, metals	3-foot-thick cap of dredged material
Elliott Bay	King County – Denny Way CSO	Corps	1990	PCBs, PAHs, metals	2.5-foot-thick cap of dredged material
Elliott Bay	Pier 51 – Coleman Dock	Corps	1989	PCBs, PAHs, metals	1.5-foot-thick cap of dredged material
Elliott Bay	Pier 53 – Washington Street CSO	Corps	1992	PCBs, PAHs, metals	1-foot-thick and 3-foot-thick cap of dredged material
Elliott Bay	Pier 64 – Port of Seattle	MTCA	1994	PCBs, PAHs, metals	1-foot-thick enhanced natural recovery layer of dredged material
Elliott Bay	Pacific Sound Resources	CERCLA	2004	PAHs	6-foot-thick sand and gravel cap, armored in places; 54-inch sand and gravel cap; 42-inch sand cap
Duwamish Waterway	Duwamish/Diagonal CSO	NRDA	2005	PCBs, mercury, phthalates	3-foot-thick sand cap or armored cap; restore grade
Duwamish Waterway	Norfolk CSO	NRDA	1998	PCBs, mercury, BEHP,1,4-dichlorobenzene	3-foot-thick sand cap; restore grade
Duwamish Waterway	West Waterway CAD	Corps	1984	PCBs, metals	2-foot-thick sand cap
Commencement Bay	Thea Foss	CERCLA	2003	Metals, PAHs, PCBs, phenols, phthalates	
Commencement Bay	Middle Waterway	CERCLA	2003	Metals, PCB, phthalates	3-foot-thick sand cap or armored cap
Commencement Bay	Head of Thea Foss	CERCLA	2003	PAHs, NAPLs	HDPE plus 3-foot-thick sand cap
Commencement Bay	Simpson Tacoma Kraft	Corps	1988	PAHs	4-foot-thick sand cap
Budd Inlet	One Tree Island Marina		1987	Metals, PAHs	4-foot-thick sand cap

Notes:

BEHP = bis(2-ethylhexyl)phthalate Corps = U.S. Army Corps of Engineers NRDA = Natural Resources Damage Assessment

CAD = confined aquatic disposal
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CSO = combined sewer outfall
MTCA = Model Toxics Control Act
NAPLs = nonaqueous phase liquid
PAHs = polynuclear aromatic hydrocarbons
PCBs = polychlorinated biphenyls

During remedial design, appropriate cap designs in different areas of the Site would be determined individually for each component based on location-specific design parameters. For the purposes of this FS, conceptual-level cap designs were developed based on a review of engineered caps designed, approved, and successfully constructed and monitored in other areas of Puget Sound, also taking into consideration site-specific habitat conditions within Port Gamble. Based on these factors, this FS developed three different cap designs for development of the alternatives, summarized in Table 4-2.

Table 4-2
Cap Designs Developed for the Feasibility Study

Cap Type	Criteria	Thickness
I	Benthic cap in intertidal areas (above -3 feet mean lower low water [MLLW]) that exceed site-specific cleanup levels or toxic porewater sulfide levels	24 inches of coarse sand and gravel
II	Benthic cap in subtidal areas (below -3 feet MLLW) without substantial wood waste deposits that exceed site-specific cleanup levels but with porewater sulfide below potentially toxic levels	12 inches of silt/sand
III	Benthic cap in geoduck subtidal areas (below -3 feet MLLW) with substantial wood waste deposits or in subtidal areas where porewater sulfide exceeds potentially toxic levels	48 inches of silt/sand

Beneficial reuse of Snohomish River maintenance dredged material or other suitable sediments will be considered during remedial design and is preferred over quarried material. The beneficial reuse of sand is subject to similar considerations for Engineered Containment as described previously for EMNR. Other potential sources of sand include the local quarry owned by PR, which was used as the primary source for the post-dredge sand cover successfully placed during the 2007 interim action. Where the local quarry does not contain sufficient quantity of sand, and for larger sized aggregates, a commercial quarry would be the likely source of cap material. For costing purposes, the cap designs summarized in Table 4-2 are considered to be the final placed thicknesses (i.e., including overplacement allowances).

Removal

Removal of sediments from the aquatic environment is a common approach to addressing materials that require remedial action, and was used during both the 2003 and 2007 interim actions at the mill site when an aggregate total of approximately 30,000 cy of woody sediments were removed. If selected as a part of the final remedy, removal of subtidal sediments would likely be performed from a barge-mounted clamshell dredge, similar to these prior actions, while intertidal sediments could be excavated under lower-tide conditions using upland-based equipment. Removal was retained as a response action for more detailed evaluation in this FS.

A number of site-specific operational conditions influence the effect of environmental dredging of contaminated sediment on aquatic systems. Experience at the site, as well as has been documented on other sediment cleanup projects, shows that resuspension of contaminated sediment and release of contaminants occur during dredging and that contaminated sediment residuals will remain following operations, which can affect the magnitude, distribution, and bioavailability of the contaminants and the exposure and risk to receptors of concern. Dredging residuals have been shown to be particularly problematic at sites with considerable debris (Patmont and Palermo 2007). Even after decades of sediment remediation project experience, there are still substantial uncertainties in our understanding of the cause-effect relationships relating dredging processes to risk reduction (EPA 2005; Bridges et al. 2008; Bridges et al. 2010).

Where removal is considered, residuals management strategies should be considered. Considerable experience from prior dredging projects shows that the historical approach of using multiple cleanup passes to address residuals is ineffective. More recently, sediment remedies have incorporated a residuals management strategy that entails placement of a post-dredge clean cover. This strategy was effectively demonstrated during the 2007 interim action conducted at the mill site. For alternatives that entail removal, a post-dredge residuals management strategy that includes placement of a nominal 6-inch-thick layer of clean sand has been incorporated as part of this general response action.

To effectively assess potential impacts from removal alternatives, and to properly compare alternatives, the volume of removal associated with each alternative must be estimated. For removal-based alternatives, the horizontal extent of dredging is considered to be either the boundary of the SMA, or an internal sub-area that is specific to a particular alternative, the limits of which are described for that particular alternative. The vertical extents of removal are based on the results of the sediment coring data where available, and supplemented by the surface sample results. For cores, the vertical limit of dredging was estimated considering sediment TVS results, where TVS greater than 15 percent is the criterion for removal of wood waste; for other contaminants, the site-specific cleanup standards or SMS criteria apply. For surface samples where core data are not available, a prospective dredge depth of 2 feet has been incorporated into the volume estimates, and will be refined during remedial design.

Because of the widespread distribution of individual sample points, and due to the uncertainty of the depth of removal in surface sample areas, it is appropriate and consistent with current sediment FS practice to "scale up" estimated dredge volumes from neatline calculations. Based on a review of historical sediment cleanup projects, appropriate scaling factors are considered to be 1.25 to 2 times the neatline estimate of dredge volumes, depending on site understanding at the time of the FS, and the level of engineering that was used in developing the volume estimate. Removal volumes calculated in this FS are based on the horizontal and vertical extents as described above and include a 1-foot overdepth allowance on the neatline dredge volumes. This volume is then further scaled up by an average factor of 1.25 for the mid-range cost estimate to 1.5 for the high-end cost estimate to accommodate potential uncertainty in actual distribution of potential contamination, and considering engineering factors such as side slopes and level cuts that would be implemented during remedial design development, consistent with recent Corps guidance (Palermo et al. 2008).

Disposal Options

There are several options for disposal of marine sediments removed through dredging. For those sediments that are determined by the DMMP to be suitable for open-water disposal, such sediments may be transported by bottom-dump barge for disposal at an unconfined open-water disposal site. Based on preliminary DMMP characterization of sediments at the Site, subtidal wood waste within portions of the Mill Site North and South SMAs could be suitable for open-water disposal at the non-dispersive DMMP site in Port Gardner near Everett, Washington. However, additional testing and suitability determinations by the

DMMP would be required during design to verify the suitability of these materials for open-water disposal.

For debris and sediments that are not suitable for open-water disposal, beneficial reuse and/or upland disposal at a permitted municipal or private landfill (e.g., construction debris landfill or Subtitle D landfill) may be necessary. Sediments excavated using water-based equipment could be loaded on a barge, and could potentially be shipped directly to a Canadian landfill, or to a barge-truck-rail transloading facility for shipment to a United States landfill with rail access. Alternately, if space permits, an on-site offloading and staging area could be set up to process sediments and debris, and load this material into trucks for off-site transport and disposal. Where chemistry results allow for potential beneficial reuse, additional alternatives for managing dredged material may be available as discussed in Section 4.3.7.2.

Reuse Options

While a specific beneficial reuse opportunity for subtidal wood waste material and/or intertidal sediments was not identified for this FS, there may be practicable opportunities to reuse some of these materials beneficially, including topsoil for upland restoration. In this case, debris would need to be screened out, larger pieces chipped, and salt rinsed (i.e., “sparged”) from the material prior to upland reuse. Successful sparging of salinity from wood debris was demonstrated as part of the 2007 interim action at the Site, where wood debris sediments were dredged from Port Gamble Bay and placed within a nearshore upland stockpile containment structure (i.e., 4-foot-thick sparging basin). Fresh water was applied through a simple sprinkler system, which successfully reduced porewater salinity within the sparging basin to below secondary drinking water standards (less than 0.5 parts per thousand [ppt]) within a period of approximately 4 months (Anchor QEA and EPI 2010). Leachate from the sparging basin did not exceed discharge criteria, and was passively returned to Port Gamble Bay. Much of the sparged Port Gamble material was successfully reused as an upland soil amendment on property owned by Olympic Property Group (OPG).

At the Site, the practicability of beneficial reuse of wood waste and/or intertidal sediments is limited by the available land to facilitate sparging, and also by logistics and costs associated with transport of sparged materials to prospective beneficial reuse locations. While specific beneficial reuse opportunities were not identified for this FS, if this option were to be selected as part of the final Site remedy, such opportunities would be further explored and evaluated during remedial design.

Ex Situ Treatment

As discussed above, ex situ treatment of wood waste and/or intertidal sediments using relatively low-cost sparging technologies has been demonstrated as a method to remove salt from the material to facilitate beneficial reuse of these materials. However, in order to be cost-effective, ex situ treatment by sparging requires a significant upland space available adjacent to the project site while sparging is performed. While other remedial technologies such as thermal desorption, incineration, and stabilization could potentially be applied to the Site, such technologies are substantially more expensive than off-site landfill disposal, and many of these technologies have limited effectiveness for sediments with a high organic content such as wood waste. Thus, no ex situ treatment technologies, other than sparging to facilitate beneficial reuse of wood waste and/or intertidal materials, are retained as general response actions.

In Situ Treatment

In situ treatment entails the direct application or placement of amendments into the sediment and/or mixing reagents with sediment cap substrate to reduce the bioavailability of certain contaminants. Selection of appropriate in situ treatment requires evaluation of available process options to determine which amendments and distribution methods are likely to be most effective for site sediment and COCs. Typical application involves the placement of activated carbon (AC) or other types of reagents that bind certain organic and/or metal contaminants. In situ treatment has been applied at sediment cleanup sites using one of five process options at the field pilot scale, including:

- Mechanical mixing of amendments into shallow sediment
- Slurry placement of the amendments onto the sediment surface
- Mixing amendments with sand, and placing the blended materials using methods similar to the EMNR or containment technology discussed above
- Sequentially placing amendments under a thin sand cover

- Broadcast application of amendments in a pelletized form to improve settling characteristics (e.g., SediMite™); the pellet matrix subsequently degrades, allowing the AC to slowly mix into surface sediments through bioturbation)

Of the amendments available, AC has received more testing and evaluation than organoclays, particularly with respect to sediment remediation, because the sorption capacities for PAHs, dioxin/furans, and other chemicals in AC are at least an order of magnitude higher than other sorbents.

While application of in situ treatment has been demonstrated to be effective and implementable at other sediment sites, Port Gamble sediments are expected to be less amenable to treatment of wood waste and wood waste degradation byproducts such as porewater sulfide. Application of in situ treatment for such COCs has not been documented and is expected to not be effective. Thus, in situ treatment was screened from further consideration as an applicable general response action.

Summary of Retained Response Actions

Table 4-3 summarizes the screening decisions for the general response actions that were carried forward for detailed evaluation in this FS.

Table 4-3

Remedial Technology and Disposal Screening Summary

General Response Action	Process Option	Screening Decision
Institutional Controls	Access and deed restrictions; informational devices	Retained
Source Control	Creosote piling and structure removal	Retained
Monitored Natural Recovery (MNR)	Natural sedimentation	Retained
Enhanced Monitored Natural Recovery (EMNR)	Place thin layer of clean cover	Retained
Engineered Containment	Capping	Retained
Removal	Soil excavators; mechanical dredging	Retained
In Situ Treatment	Adsorptive amendments; stabilization	Not Retained
Ex Situ Treatment	Stabilization	Not Retained
	Washing (sparging)	Retained
	Incineration	Not Retained
	Thermal desorption	Not Retained
Disposal	Upland beneficial reuse	Retained
	Upland landfill disposal	Retained
	Open-water disposal	Retained

EVALUATION BASIS

Remedy selection criteria under the SMS regulations are similar to those required under MTCA. The SMS evaluation criteria are specified in WAC 173-204-560(4)(f) through (k). This section describes the requirements for cleanup action evaluations under the SMS.

Threshold Criteria

Cleanup actions performed under the SMS must comply with two basic, or "threshold" requirements. Alternatives that do not comply with threshold criteria would typically not be considered suitable cleanup actions under the SMS. The SMS threshold requirements are:

- Overall protection of human health and the environment
- Attainment of cleanup standards

Overall Protection of Human Health and the Environment

The overall protectiveness of a cleanup action alternative is evaluated based on several factors. Primary considerations include the extent to which human health and the environment are protected and the degree to which overall risk at a site is reduced. Both on-site and off-site reductions in risk are considered. Protectiveness also gauges the degree to which the cleanup action may perform above the level of the specific standards presented in the SMS. Finally, protectiveness is a measure of the improvement in the overall environmental quality at the site. This criterion also includes consideration of whether the alternative is likely to achieve site-specific cleanup standards within a 10-year time frame.

Attainment of Cleanup Standards

This threshold criterion evaluates whether the alternative meets the site-specific cleanup standards selected in the RI. In addition, SMS specifies that cleanup actions must comply with federal, state, and local laws. For SMAs where no alternative can attain site-specific cleanup standards within the 10-year time frame specified in SMS, an additional technical practicability evaluation is required as described subsequently in this section.

Additional SMS Evaluation Criteria

This section describes the specific factors that are considered under each of the SMS criteria when evaluating an alternative, and the parameters that would lead to a relatively lower or higher score. For scoring each alternative, the criteria use a weighting factor to reflect the relative importance of the factor in the overall assessment of the alternative. Each weighting factor is provided in the discussion below.

Short-term Effectiveness

Evaluation of this criterion considers the relative magnitude and complexity of actions required to maintain protection of human health and the environment during implementation of the cleanup action. Cleanup actions carry short-term risks, such as potential mobilization of contaminants during construction (e.g., dredge residuals as discussed in Section 4), or safety risks typical of large construction projects. Other impacts to short-term effectiveness include water quality degradation, noise, vessel and vehicle traffic, and air emissions. Some short-term risks can be managed to some degree through the use of best practices during project design and construction, while other risks are inherent to project alternatives. Those activities that result in unavoidable environmental or safety impacts during construction are considered to have a lower ranking than those activities that result in minimal impact. For similar types of activities (which would typically have similar impacts over the same time period), longer duration actions would rank lower for short-term effectiveness than shorter duration actions.

The short-term effectiveness criterion has been given a weighting factor of 10 percent—i.e., the absolute score described in Section 6 is multiplied by 0.10 when summing the total alternative score. This relatively low weighting factor recognizes that active construction alternatives will all have a short-term impact regardless of the technology used.

Long-term Effectiveness

Long-term effectiveness is a parameter that expresses the degree of certainty that the alternative will be successful in maintaining compliance with cleanup standards over the long-term performance of the cleanup action.

The highest long-term effectiveness ranking is given to those alternatives that remove wastes and toxic sediments from the aquatic environment and effectively treat or contain them in confined disposal facilities. Moderate ranks are assigned to alternatives that effectively cap or contain sediments in place and prevent human and ecological exposures. Lower long-term effectiveness rankings are applied for technologies such as EMNR, MNR, and institutional controls. The regulations recognize that, in most cases, the cleanup alternatives will combine multiple technologies to accomplish the cleanup action objectives.

The long-term effectiveness factor has been given a weighting of 30 percent, the highest of the criteria. This relatively high factor reflects that the long-term outcome is of primary importance when assessing the value of an alternative.

Implementability

Implementability is an overall metric expressing the relative difficulty and uncertainty of implementing the cleanup action. Evaluation of implementability includes consideration of technical factors such as the availability of mature technologies, materials, and experienced contractors to accomplish the cleanup work. Implementability is also related to project duration in that longer construction projects can have significantly more impact on the access to and use of the bay for recreational and tribal fishing and shellfish harvest activities, and thus are more difficult to implement from a coordination standpoint, particularly when construction spans multiple in-water work seasons and must start and stop a number of times before completion. The evaluation of implementability also includes administrative factors associated with the ability and time required to obtain any necessary approvals and permits from other agencies for the cleanup activities.

Implementability has been given a weighting factor of 20 percent in the overall scoring. This weighting factor recognizes the important real-world considerations surrounding implementability in that alternatives with low implementability scores have a very low likelihood of actually being accomplished on the ground.

Cost

The analysis of cleanup action alternative costs includes all costs associated with implementing an alternative, including design, construction, long-term monitoring, and institutional controls. Costs between the different alternatives are compared to assist in the overall analysis of relative costs and benefits of the alternatives. The costs to implement an alternative include the net present value of any long-term costs (e.g., operation and maintenance, monitoring, equipment replacement, and maintaining institutional controls), along with agency oversight costs. Cost estimates for removal and disposal technologies include processing, analytical, labor, and waste management costs.

The FS scoring for cost was based on the overall cost per acre of each alternative. Alternatives that cost less than $250,000 per acre were assigned the highest score, and those that cost more than $1 million per acre were assigned the lowest score according to the scheme presented in Table 5-1.

Table 5-1
Evaluation Scoring for Estimated Cost

Evaluation Score	Estimated Cost Range
1	Greater than $1 million/acre
2	$750,000 to $1 million/acre
3	$500,000 to $750,000/acre
4	$250,000 to $500,000/acre
5	Less than $250,000/acre

Cost has been given a weighting factor of 25 percent. This relatively high factor is a reflection of the reality that cleanup funds, from both a private and public perspective, are limited. The intent of this weighting factor is to balance cost-effectiveness against the benefits associated with the other assessment criteria.

Consideration of Public Concerns

The public involvement process under SMS is used to identify potential public concerns regarding cleanup action alternatives. The extent to which an alternative addresses those concerns is considered as part of the evaluation process. This includes concerns raised by individuals, community groups, local governments, tribes, federal and state agencies, local businesses, and other organizations with an interest in the site. Potential impacts to cultural resources from a given remedy and potential impacts to tribal use of the bay during remedy implementation are considered under this evaluation criterion. Ecology will continue to evaluate public concerns through the public involvement process as the CAP is developed.

Input from members of the community is used to shape the remedial actions with respect to timing, local or cultural considerations, effects from disturbances including noise, light, and traffic that result from implementation methods or transportation routes, etc. It is recognized that different members of the community may have different priorities, and these priorities may or may not be aligned with the goals of the cleanup and/or the specific requirements of SMS.

The weighting factor for community concerns is 5 percent in selecting the preferred alternative. However, substantial input was received during the RI/FS process that has been carefully taken into account in designing the remedial investigations and developing the alternatives. In addition, tribal, federal, state, and local government involvement will occur during planning, design, and implementation of the preferred alternatives to ensure that cultural and community impacts are minimized and that all applicable regulations and guidance are followed.

Use of Recycling, Reuse, and Waste Minimization

The use of recycling, reuse, and waste minimization for a given alternative considers whether materials can effectively be beneficially reused. Opportunities include beneficial use of woody debris and/or intertidal sediments dredged or excavated during cleanup actions, and beneficial reuse of suitable dredged sediments for residuals cover or cap materials that would otherwise be disposed of in a DMMP open-water disposal site. Finally, there may be opportunities to beneficially reuse wooden demolition debris (including wharf structures and/or creosoted piles) as fuel for power generation. Specific beneficial reuse opportunities for sediment or demolition materials have not been identified for this FS, although they have been demonstrated previously as discussed in Section 4. Beneficial reuse of suitable sediments for cover and cap material can result in significant cost efficiency and is desirable from a resource standpoint. Ecology, DNR, and OPG will continue to explore opportunities and sources of beneficial reuse materials in greater detail during remedial design.

A weighting factor of 5 percent was selected for this evaluation criterion. While the use of recycling and waste minimization in the context of a cleanup is an important goal, recycling and waste minimization are inherent to efficient and cost-effective construction projects, and there will be a natural tendency to maximize this element of a project during implementation.

Consideration of Environmental Impacts

Environmental impacts are associated with construction activities during remedy implementation. Per SMS, this evaluation should consider the following:

- Significant short-term environmental impacts
- Significant long-term environmental impacts
- Significant irrevocable commitments of natural resources
- Significant environmental impacts that cannot be mitigated

Short term-impacts to water quality, including turbidity and ammonia or sulfide release associated with dredging and turbidity associated with capping, are considered under this criterion. In addition, emissions related to the construction activity, both on the water and off site (through transloading and shipment of materials) are also considered. Irrevocable commitments of natural resources are also considered, such as the use of aggregates from commercial or other sources for cap material and the use of fossil fuel for construction equipment.

Environmental impacts were given a weighting factor of 5 percent. This relatively low factor reflects the fact that environmental impacts are also considered, to some degree, under the evaluation of short-term effectiveness, implementability, consideration of public concerns, and the use of recycling and waste minimization. In addition, a SEPA evaluation will be conducted along with or prior to the CAP.

Technical Practicability Evaluation

For a given SMA where no alternative can practicably achieve cleanup standards within a 10-year time frame, the SMS allows for establishment of a sediment recovery zone (WAC 173-205-590) provided that the establishment of the sediment recovery zone "shall not be used as a substitute for active cleanup actions, when such actions are practicable and meet the standards of WAC 173-204-580." Where a sediment recovery zone is proposed, the cleanup study plan shall include a discussion of the following:

- The time period during which a sediment recovery zone is projected to be necessary
- The legal location and landowner(s) of property proposed as a sediment recovery zone
- Operational terms and conditions including, but not limited to, proposed monitoring actions for the sediment recovery zone
- Potential risks posed by the proposed sediment recovery zone to human health and the environment
- The technical practicability of elimination or reduction of the size and/or degree of chemical contamination and/or level of biological effects within the proposed sediment recovery zone
- Current and potential use of the sediment recovery zone, surrounding areas, and associated resources that are, or may be, affected by releases from the zone
- The need for institutional controls or other site use restrictions to reduce site contamination risks to human health

As discussed in Section 6 of this FS, a technical practicability evaluation was performed for SMA-5, in which no alternative can reasonably achieve the site-specific cleanup standards within the 10-year time frame. The practicability evaluation considers environmental effects, technical feasibility, and cost, as defined under SMS (WAC-173-204-200(19)) for construction of either a dredging, capping or EMNR remedy in SMA-5.

DEVELOPMENT AND EVALUATION OF CLEANUP ACTION ALTERNATIVES

In this section, the technologies and process options for cleanup technologies retained through the screening evaluation described in Section 4 are used to develop alternatives to address the cleanup action objectives for impacted areas and media at the Site. This section also provides a comparative analysis of the cleanup action alternatives. Each alternative addresses impacted media with a combination of technologies appropriate for Site conditions.

The cleanup action alternatives developed in this section are based on conceptual-level designs for the implementation of individual technologies described in Section 4. The design parameters used to develop the alternatives are based on engineering judgment and current knowledge of Site conditions. The final design for the preferred alternatives may require additional characterization and analysis to refine the scope and costs associated with the selected cleanup action.

This section describes the cleanup action alternatives, an initial screening of appropriate remedial technologies for each SMA, and the evaluation and comparison of the alternatives. A summary of the evaluation is presented in Table 6-1. Estimated costs for the alternatives are summarized in Table 6-2, and estimated volumes and durations for the alternatives are summarized in Table 6-3.

Table 6-1
Alternative Scoring Summary

SMA	Alternative	Protection of Human Health and the Environment[a]			Attainment of Cleanup Standards and Compliance with Laws[b]		Short-term Effectiveness[c]			Long-term Effectiveness[d]					Ability to be Implemented[e]				Cost[f]	Community Concerns[g]	Recycling, Reuse, Waste Min.[h]	Environmental Impacts[i]	
		Human Health	Environment	Time to Achieve Standards	Cleanup Standards	Applicable laws	Human Health	Environment	Score	Environment	Human Health	Certainty and Reliability	Residual Risks	Score	Technical Feasibility	Availability of Materials, Land, etc.	Permitting and Regulatory	Score	Estimated Average Cost Score	Score	Score	Score	Total Score
Mill Site North	1 - Dredge	Y	Y	Y	Y	Y	3	4	3.5	5	5	4	4	4.5	4	5	5	4.7	1	5	2	4	69
	2 - Dredge and Cap	Y	Y	Y	Y	Y	4	4	4.0	5	5	4	3	4.3	4	5	5	4.7	2	3	3	4	72
	3 - Cap	Y	Y	Y	Y	Y	5	4	4.5	4	5	3	3	3.8	5	5	5	5.0	3	1	3	4	75
	4 - Cap and EMNR	Y	Y	Y	Y	Y	5	5	5.0	3	5	2	2	3.0	5	5	5	5.0	3	1	3	4	71
Mill Site South	1 - Dredge	Y	Y	Y	Y	N	1	1	1.0	5	5	4	4	4.5	3	2	4	3.0	1	5	2	1	54
	2 - Dredge and Cap	Y	Y	Y	Y	Y	2	1	1.5	5	5	4	3	4.3	3	3	5	3.7	1	4	3	3	58
	3 - Dredge and Cap II	Y	Y	Y	Y	Y	3	2	2.5	4	5	4	3	4.0	4	4	5	4.3	2	3	4	3	66
	4 - Dredge, Cap, and EMNR	Y	Y	Y	Y	Y	4	4	4.0	4	5	4	3	4.0	4	4	5	4.3	3	2	4	4	74
	5 - Cap	Y	Y	Y	Y	Y	5	5	5.0	4	5	3	3	3.8	5	4	5	4.7	4	1	5	3	80
	6 - Cap and EMNR	Y	Y	Y	Y	Y	5	5	5.0	3	5	2	1	2.8	5	4	5	4.7	4	1	5	4	75
Central Bay	1 - Dredge	Y	Y	Y	Y	N	1	1	1.0	5	5	2	4	4.0	2	1	2	1.7	2	2	2	1	48
	2 - Cap	Y	Y	Y	Y	Y	5	3	4.0	4	5	4	3	4.0	4	3	5	4.0	5	3	5	2	83
	3 - EMNR	Y	Y	Y	Y	Y	5	5	5.0	3	5	4	2	3.5	5	4	5	4.7	5	4	5	3	87
	4 - MNR	N	N	N	N	N	1	1	1.0	2	1	1	1	1.3	5	5	5	5.0	5	1	1	5	62
FLA	1 - Dredge	Y	Y	Y	Y	Y	1	1	1.0	5	5	5	4	4.8	3	3	5	3.7	2	4	2	3	64
	2 - Cap	Y	Y	Y	Y	Y	5	4	4.5	4	5	5	3	4.3	4	5	5	4.7	5	4	5	4	91
	3 - EMNR	Y	Y	Y	Y	Y	5	5	5.0	4	5	4	3	4.0	5	5	5	5.0	5	3	5	4	91
	4 - MNR	N	N	N	N	N	1	1	1.0	2	1	1	1	1.3	5	5	5	5.0	5	1	1	5	62
Background	1 - Dredge and MNR	N	Y	N	N	N	1	1	1.0	3	2	2	4	2.8	2	1	2	1.7	2	1	2	1	39
	2 - Cap and MNR	N	Y	N	N	N	2	2	2.0	3	2	3	3	2.8	3	2	4	3.0	5	2	5	2	67
	3 - EMNR and MNR	N	Y	N	N	N	2	3	2.5	4	2	2	2	2.5	4	3	5	4.0	5	2	5	3	71
	4 - MNR	N	Y	N	N	N	1	5	3.0	5	1	1	1	2.0	5	5	5	5.0	5	1	1	5	70

Notes:

Does not meet threshold criteria
Highest scoring alternatives (within a few points)
Draft preferred alternative

EMNR = enhanced, monitored natural recovery
FLA = former lease area
MNR = monitored natural recovery
SMA = Sediment Management Area

1 = Low
2 = Low-medium
3 = Medium
4 = Medium-high
5 = High

a = Overall protection of human health and the environment, time required to attain the cleanup standard(s), and on-site and off-site environmental impacts and risks to human health resuling from implementing the cleanup alternatives.
b = Attainment of the cleanup standard(s) and compliance with applicable federal, state, and local laws.
c = Short-term effectiveness, including protection of human health and the environment during construction and implementation of the alternative.
d = Long-term effectiveness, including degree of certainty that the alternative will be successful, long-term reliability, magnitude of residual biological and human health risk, and effectiveness of controls for ongoing discharges and/or controls required to manage treatment residues or remaining waste cleanup and/or disposal site risks.
e = Ability to be implemented, including the potential for landowner cooperation, consideration of technical feasibility, availability of needed off-site facilities, services and materials, administrative and regulatory requirements, scheduling, monitoring requirements, access for construction, operations and monitoring, and integration with existing facility operations and other current or potential cleanup actions.
f = Cost, including consideration of present and future direct and indirect capital, operation, and maintenance costs and other foreseeable costs.
g = The degree to which community concerns are addressed.
h = The degree to which recycling, reuse, and waste minimization are employed.
i = Environmental impact. Sufficient information shall be provided to fulfill the requirements of the State Environmental Policy Act. Discussions of significant short-term and long-term environmental impacts, significant irrevocable commitments of natural resources, significant alternatives including mitigation measures, and significant environmental impacts which cannot be mitigated shall be included.

Table 6-2
Estimated Cost Summary

	Estimated Total Cost	Estimated Cost/Acre
Mill Site North - SMA-1 (6 acres)		
Alt 1 - Dredge	$6,600,000	$1,100,000
Alt 2 - Dredge and Engineered Cap	$5,300,000	$880,000
Alt 3 - Engineered Cap	$4,300,000	$720,000
Alt 4 - Engineered Cap and EMNR	$4,200,000	$700,000
Mill Site South - SMA-2 (19 acres)		
Alt 1 - Dredge	$30,700,000	$1,620,000
Alt 2 - Dredge and Engineered Cap I	$21,400,000	$1,130,000
Alt 3 - Dredge and Engineered Cap II	$16,300,000	$860,000
Alt 4 - Dredge, Engineered Cap, and EMNR	$9,600,000	$510,000
Alt 5 - Engineered Cap	$7,100,000	$400,000
Alt 6 - Engineered Cap and EMNR	$7,000,000	$370,000
Central Bay - SMA-3 (77 acres)		
Alt 1 - Dredge	$60,500,000	$790,000
Alt 2 - Engineered Cap	$4,900,000	$60,000
Alt 3 - EMNR	$2,800,000	$40,000
Alt 4 - Monitored Natural Recovery	$300,000	$4,000
Former Lease Area - SMA-4 (19 acres)		
Alt 1 - Dredge	$15,700,000	$830,000
Alt 2 - Engineered Cap	$1,800,000	$90,000
Alt 3 - EMNR	$1,300,000	$70,000
Alt 4 - Monitored Natural Recovery	$150,000	$8,000
Background - SMA-5 (cPAH Area - 196 acres)		
Alt 1 - Dredge	$152,400,000	$780,000
Alt 2 - Engineered Cap	$11,600,000	$60,000
Alt 3 - EMNR	$6,100,000	$30,000
Alt 4 - Monitored Natural Recovery	$400,000	$2,000

Notes:

1. Costs include engineering, design, permitting, and construction management, which range from 25% to 35% of overall total.

2. Estimated costs assume some open-water disposal for dredge material (80% for Mill Site North, 25% for Mill Site South, 50% for all other SMAs), mining of cap and EMNR cover sand from an open-water or beneficial reuse site, and 1.25x scaling factor on preliminary dredge volumes, consistent with recent sediment FS guidance.

Table 6-3
Estimated Volume and Duration Summary

	Dredge Vol (cy)	Cap Vol (ton)	Duration (days)	Duration (seasons)
Mill Site North - SMA 1 (6 acres)				
Alt 1 - Dredge	41,000	6,900	58	0.7
Alt 2 - Dredge and Engineered Cap	18,425	16,400	33	0.4
Alt 3 - Engineered Cap	5,300	26,100	20	0.3
Alt 4 - Engineered Cap and EMNR	5,300	22,500	18	0.2
Mill Site South - SMA 2 (19 acres)				
Alt 1 - Dredge	170,700	23,200	239	3.0
Alt 2 - Dredge and Engineered Cap I	109,000	40,600	166	2.1
Alt 3 - Dredge and Engineered Cap II	71,900	77,000	134	1.7
Alt 4 - Dredge, Engineered Cap, and EMNR	33,200	91,800	90	1.1
Alt 5 - Engineered Cap	9,100	116,400	70	0.9
Alt 6 - Engineered Cap and EMNR	9,100	112,300	68	0.9
Central Bay - SMA 3 (77 acres)				
Alt 1 - Dredge	466,000	93,200	668	8.5
Alt 2 - Engineered Cap	-	186,300	93	1.2
Alt 3 - EMNR	-	93,200	47	0.6
Alt 4 - Monitored Natural Recovery	-	-	-	-
Former Lease Area - SMA 4 (19 acres)				
Alt 1 - Dredge	116,000	23,100	166	2.1
Alt 2 - Engineered Cap	-	46,200	23	0.3
Alt 3 - EMNR	-	23,100	12	0.2
Alt 4 - Monitored Natural Recovery	-	-	-	
Background - SMA-5 (cPAH Area - 196 acres)				
Alt 1 - Dredge	1,190,000	237,900	912	11.5
Alt 2 - Engineered Cap	-	475,900	238	3.0
Alt 3 - EMNR	-	237,900	119	1.5
Alt 4 - Monitored Natural Recovery	-	-	-	-

Notes:

1. Cap production rate assumed to be 2,000 tons/day; fish window assumed to be Nov. 15 to Feb. 15; work week assumed to be 6 days.
2. For SMA-1 through SMA-4, dredge production rate assumed to be 750 cy/day.
3. For SMA-5, dredge production rate assumed to be 1,500 cy/day.
4. Volumes based on "Mid-Range Estimate" scenario from each detail spreadsheet.

Initial Screening of Technologies for SMAs

While Section 4 provided a general screening for all remedial technologies that would be considered for sediments, the retained technologies were further screened for application to specific SMAs based on SMA-specific considerations. This section provides an initial screening of alternatives relative to the SMAs, and summarizes the alternatives that were carried forward for detailed evaluation.

Mill Site North (SMA-1)

Located in the northern embayment, the Mill Site North SMA (SMA-1) contains a buried deposit of wood chips extending approximately 6 feet below mudline, identified by the existing core data to be primarily located in the shallow subtidal zone (between 4 and 15 feet below MLLW). This SMA is characterized by relatively high surface sediment porewater sulfide concentrations, as well as CSL-level amphipod and SQS-level larval bioassay exceedances (Ecology 2012). The Mill Site North area is also characterized by elevated cPAH in surface sediments, with values ranging from 2 to 6 times above background in this area.

Existing structures in this SMA are supported by creosoted piles. As part of the remedy and for cPAH source control, all creosoted pilings and structures will be removed.

A range of remedial technologies including dredging, dredging combined with engineered containment (dredge and cap), capping, and capping combined with EMNR were evaluated as potentially appropriate remedial alternatives to address wood waste and associated biological impacts in SMA-1.

The engineered cap in SMA-1 would need to be able to attenuate porewater sulfide generated by the biochemical reaction of sulfate in marine water with underlying decomposing wood waste. Based on detailed cap performance modeling conducted for similar projects in the Puget Sound region, an engineered cap in the absence of dredging (which would remove sulfide source material) may need to provide an approximate 5- to 10-foot-long flow path of clean sand to attenuate sulfide, which can often be achieved with a 1- to 4-foot-thick cap (e.g., Anchor and Aspect 2004). The protectiveness of the 1- to 4-foot-thick caps as they relate to site-specific flow paths and tidal flux would be confirmed during remedial design.

EMNR and MNR do not address the sulfide impacts from the wood waste area of the Mill Site North. Thus, both of these technologies will only be considered protective outside of the footprint of the chip deposit in SMA-1.

Dredge Alternative Description

Geophysical survey and sediment coring work performed in the northern embayment identified a concentrated shallow subtidal deposit of wood chips within the footprint of the former chip loading facility. This deposit is located directly below surface sediments containing elevated porewater sulfide concentrations. Removal of this wood chip deposit, as well as removal of sediments that exceed site-specific cleanup levels in the biologically active zone, is the goal of the SMA-1 dredging alternative. Dredging in SMA-1 entails the following major elements:

- Demolition and removal of the existing creosoted structures and piles as practicable, or cut off to a depth of 2 feet below the sediment surface in SMA-1.
- Dredging of approximately 10,000 to 15,000 cy (including overdredge allowances) of wood chips and associated shallow subtidal (and possibly intertidal) sediments located in the vicinity of the former chip loading dock. Based on the combined sediment coring and sub-bottom profiling data, which delineated the extent of wood chips in SMA-1, dredging would extend over an area of approximately 0.9 acres.
- Dredging of 22,000 to 35,000 cy (including overdredge allowances) of sediments outside the footprint of the chip deposit throughout the remainder of the SMA. The FS assumes a target depth of 2 feet, with a 1-foot allowable overdepth for volume estimates.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site—presumed to be Port Gardner in Everett. While early DMMP screening performed on the approximately 10,000 to 15,000 cy of wood chips and

associated shallow subtidal sediments located in the vicinity of the former chip loading dock indicates that these materials are likely suitable for open-water disposal, sediments outside of the chip footprint have not been tested relative to DMMP criteria. In addition, although SMA-1 surface sediment cPAH levels are above human health risk levels, wood chips and associated shallow subtidal sediments near the former chip loading dock are below DMMP screening criteria. The percentage of SMA-1 dredge material considered "suitable" for open-water disposal is a partial data gap, due in part to evolving agency guidance on appropriate dioxin/furan levels. This FS assumes that roughly 80 percent of SMA-1 dredge material would be suitable for open-water disposal, with the remaining unsuitable material disposed of off-site in an upland landfill. The suitability of material for disposal at a DMMP open-water site requires evaluation for protection of the benthic community and may differ from levels established based on protection of human health at the reasonable maximum exposure scenario.

- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint.
- Performing compliance monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 3 months (Table 6-3). Figure 6-1 presents the Dredge alternative in SMA-1.

Dredge and Cap Alternative Description

Focused removal of the wood chip deposit is the goal of the SMA-1 dredge and cap alternative. The geophysical survey delineated the general limits of the wood chip deposit; coring data collected in this area verified the accuracy of this delineation within SMA-1. Dredging and capping in SMA-1 entails the following major elements:

- Demolition and removal of creosoted structures and piling in SMA-1.
- Intertidal excavation and upland reuse and/or disposal of sediments. Depending on the distributions of chemical concentrations within the intertidal area, up to approximately 5,000 cy of material may need to be excavated (likely using upland-based equipment operating during relatively low tidal conditions) to a depth of 2 feet

below the existing sediment surface. This material may either be reused as appropriate in upland areas near the Site, or disposed of off-site in an upland landfill. Screening-level sampling and testing in the intertidal sediments from SMA-1 conducted by OPG/PR suggests that dioxin and/or cPAH concentrations in these materials may exceed MTCA soil cleanup levels for unrestricted residential use, but are likely within protective levels for potential park, open-space, commercial, or other non-ground-floor residential uses if appropriately confined and subjected to institutional controls.

- Dredging of approximately 10,000 to 15,000 cy (including overdredge allowances) of wood chips and associated sediments located in the vicinity of the former chip loading dock.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site, if suitable.
- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint.
- Placing a nominal 2-foot-thick post-excavation backfill over the intertidal excavation footprint.
- Placing a nominal 1-foot-thick benthic cap over the remainder of the SMA to manage sediments that exceed cleanup levels.
- Implementing institutional controls for the area where caps are used. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 2 months (Table 6-3). Figure 6-2 presents the Dredge and Cap alternative in SMA-1.

Cap Alternative Description

A cap-only alternative in SMA-1 will require consideration of a thicker cap over the shallow subtidal chip deposit due to tidal pumping in this zone, which will need to be attenuated to reduce porewater sulfide levels to below the DMMP screening criterion of 3.4 mg/L. The capping alternative in SMA-1 entails the following major elements:

- Demolition and removal of creosoted structures and piles as practicable, or cut off to a depth of 2 feet below the sediment surface, in SMA-1.
- Intertidal excavation and upland reuse and/or disposal (as appropriate) of an estimated 5,000 cy of sediments.
- Placing a nominal 4-foot-thick benthic cap over the chip deposit to separate sediments containing elevated porewater sulfide levels, prevent tidal inundation into this deposit, and attenuate the generation of porewater sulfide within the cap.
- Placing a nominal 2-foot-thick post-excavation backfill over the intertidal excavation footprint.
- Placing a nominal 1-foot-thick benthic cap over the remainder of the SMA to manage sediments that exceed cleanup levels.
- Implementing institutional controls for the area where caps are used. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 1 to 2 months (Table 6-3) provided that a sufficient supply of sand can be procured over this time frame (see Section 4). Figure 6-3 presents the Cap alternative in SMA-1.

Cap and EMNR Alternative Description

A cap and EMNR alternative in SMA-1 makes use of EMNR outside of the footprint of the chip deposit with the intent of accelerating recovery of those areas where bioassay results indicate exceedance of cleanup levels. This alternative includes:

- Demolition and removal of creosoted structures and piles as practicable, or cut off to a depth of 2 feet below the sediment surface, in SMA-1.
- Intertidal excavation and upland beneficial reuse and/or disposal (as appropriate) of an estimated 5,000 cy of sediments.

- Placing a nominal 4-foot-thick benthic cap over the chip deposit to separate sediments containing elevated porewater sulfide levels, prevent tidal inundation into this deposit, and attenuate the generation of porewater sulfide within the cap.
- Placing a nominal 2-foot-thick post-excavation backfill over the intertidal excavation footprint.
- Placing a nominal 6-inch-thick EMNR cover over the remainder of the SMA to accelerate recovery of sediments that exceed cleanup levels.
- Implementing institutional controls for the area where caps are used. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 1 month (Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-4 presents the Cap and EMNR alternative in SMA-1.

Mill Site South (SMA-2)

Located in the southern embayment, the Mill Site South SMA (SMA-2) also contains a buried deposit of wood chips in shallow subtidal and deeper subtidal zones that averages approximately 5 to 10 feet thick depending on location. Unlike SMA-1, the thicker portion of the deposit is located in deeper water (more than 20 feet below MLLW). Porewater sulfide has not been detected in samples collected from deeper areas of this SMA (below -20 feet MLLW), but evidence for the presence of sulfides (e.g., *Beggiatoa* colonies) was evident at shallower depths (above -20 feet MLLW) in underwater videos obtained during the 2007 dredging event. While lower surface sediment porewater sulfide concentrations were reported throughout SMA-2 (Ecology 2012), the presence of subsurface *Beggiatoa* mats in the wood waste in this area indicates similar dynamics to SMA-1, particularly within the shallow subtidal zone (between -4 and -20 feet MLLW).

A range of remedial technologies including dredging, dredge and cap (three different dredge footprints), capping, and capping combined with EMNR were identified as potentially appropriate remedial alternatives to address wood waste and associated biological impacts in SMA-2.

Dredge Alternative Description

This alternative targets full removal of potentially impacted sediments within the footprint of SMA-2. Dredging to the maximum extent practicable in SMA-2 entails the following major elements:

- Demolition and removal of creosoted structures and existing creosoted piles as practicable, or cut off to a depth of 2 feet below the sediment surface, in SMA-2.
- Dredging an estimated 90,000 to 130,000 cy (including overdredge allowances) of wood chips, sawdust, bark, and associated sediments with TVS exceeding 15 percent.
- Dredging an estimated 50,000 to 70,000 cy of additional sediments that exceed cleanup levels over the remainder of the SMA footprint.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site. The percentage of SMA-2 dredge material potentially "suitable" for open-water disposal is currently not well characterized. However, preliminary screening of SMA-2 sediments conducted by OPG/PR suggests that only roughly 25 percent of the entire SMA-2 sediment dredge prism under this alternative would likely be suitable for open-water disposal due to elevated PAH and/or dioxin/furan concentrations. Thus, the FS assumes that 25 percent of SMA-2 dredge material would be suitable for open-water disposal, with the remaining unsuitable material disposed of off-site in an upland landfill.
- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint.
- Performing compliance monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 3 years (Table 6-3), considering the anticipated in-water construction windows that are typically required for marine construction projects, which would require significant stretches of time (February 15 to November 15, based on past experience in this area) when in-water construction would not be allowed. Figure 6-5 presents the conceptual Dredge alternative for SMA-2.

Dredge and Cap Alternative Description

The Dredge and Cap alternative considers a reduced dredge footprint that is focused on the estimated area of sediments exceeding the 15 percent TVS criterion in SMA-2, with the additional overlay that the area of the 2007 Interim Action would be re-visited by placing a nominal 6-inch-thick cover of clean EMNR sediment. Areas outside of the 15 percent TVS footprint are addressed either with an intertidal dredge and cap action, or a cap action. The Dredge and Cap alternative in SMA-2 entails the following major elements:

- Demolition and removal of creosoted structures and all creosoted piles as practicable, or cut off to a depth of 2 feet below the sediment surface, in SMA-2.
- Intertidal excavation and upland reuse and/or disposal of sediments. Based on screening-level sampling conducted by OPG/PR within the intertidal area, up to 9,000 cy of material may need to be excavated (likely using upland-based equipment operating during relatively low tidal conditions) to a depth of 2 feet below mudline. This material may either be reused as appropriate in upland areas near the Site, or disposed off-site in an upland landfill.
- Dredging an estimated 80,000 to 120,000 cy (including overdredge allowances) of wood chips and sediments with TVS exceeding 15 percent.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site, and upland beneficial reuse or disposal for material that is not suitable.
- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint and the previously dredged area.
- Placing a nominal 2-foot-thick post-excavation backfill over the intertidal and shallow subtidal excavation footprint.
- Placing a nominal 1-foot-thick benthic cap over the remainder of the SMA to manage sediments that exceed cleanup levels.

- Implementing institutional controls for the area where caps are used. Institutional controls would, at a minimum include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 2 years (Table 6-3), with consideration of anticipated in-water work windows as described previously, and provided that a sufficient supply of sand can be procured over this time frame. Figure 6-6 presents the conceptual Dredge and Cap alternative in SMA-2.

Dredge and Cap II Alternative Description

The Dredge and Cap II alternative considers a smaller dredge footprint than the Dredge and Cap alternative for SMA-2. Dredging in this alternative is focused on the estimated area of sediments exceeding TVS criteria in the north area of SMA-2, where chip deposits are thicker and potentially more affected by tidal pumping, particularly within the shallow subtidal zone. This alternative also includes the additional overlay of the 2007 Interim Action being addressed with a nominal 6-inch-thick cover of clean EMNR sediment. TVS areas that are not dredged in the Dredge and Cap II Alternative would receive a 4-foot-thick benthic cap due to the potential presence of geoducks in this area and the remaining wood waste deposits in the sediments. Areas outside of the TVS footprint are addressed either with an intertidal dredge and backfill action, or a 1-foot-thick benthic cap. The Dredge and Cap II alternative in SMA-2 entails the following major elements:

- Demolition and removal of creosoted structures and all creosoted piles as practicable, or cut off to a depth of 2 feet below the sediment surface, in SMA-2.
- Intertidal excavation and upland beneficial reuse and/or disposal (as appropriate) of an estimated 9,000 cy of sediments.
- Dredging an estimated 50,000 to 75,000 cy (including overdredge allowances) of wood chips and sediments from the northern area of the SMA where TVS exceeds 15 percent.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site.

- Beneficial reuse and/or upland disposal for materials determined unsuitable for DMMP open-water disposal.
- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint and previously dredged area.
- Placing a nominal 2-foot-thick post-excavation backfill over the intertidal and shallow subtidal excavation footprint.
- Placing a nominal 4-foot-thick cap over areas exceeding 15 percent TVS that are not dredged.
- Placing a nominal 1-foot-thick benthic cap over the remainder of the SMA to manage sediments that exceed cleanup levels.
- Implementing institutional controls for the area where caps are used. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 1.5 to 2 years (Table 6-3), with consideration of anticipated in-water work windows as described previously, and provided that a sufficient supply of sand can be procured over this time frame. Figure 6-7 presents the conceptual Dredge and Cap II alternative in SMA-2.

Dredge, Cap, and EMNR Alternative Description

The Dredge, Cap, and EMNR alternative in SMA-2 considers a smaller dredge footprint than the Dredge and Cap II alternative. Dredging in this alternative is focused on the estimated area of sediments exceeding TVS criteria in the north area of SMA-2, at elevations shallower than -20 feet MLLW (Figure 6-8), to focus dredging within the more productive photic zone and also to target the zone of elevated sulfide concentrations, while concurrently minimizing dredging of relatively deeply buried sediments that are likely unsuitable for open-water disposal due to elevated cPAH and dioxin/furan levels. Based on preliminary screening-level sampling conducted by OPG/PR, approximately 50 percent of SMA-2 dredge material under this alternative could potentially be suitable for open-water disposal, with the remaining unsuitable material either beneficially reused near the site or disposed off-site in an upland landfill. This alternative also includes the additional overlay of the 2007 Interim Action being addressed with a nominal 6-inch-thick cover of clean EMNR sediment. Areas with

TVS concentrations above 15 percent that are not dredged in the Dredge, Cap, and EMNR Alternative would receive a 4-foot-thick benthic cap due to the potential presence of geoducks in this area and the remaining wood waste deposits in the sediments. Areas outside of the TVS footprint are treated either with an intertidal dredge and cap action, or a 6-inch-thick EMNR cover. The Dredge, Cap, and EMNR alternative in SMA-2 entails the following major elements:

- Demolition and removal of creosoted structures and all creosoted piles as practicable, or cut off to a depth of 2 feet below the sediment surface, in SMA-2.
- Intertidal excavation and upland beneficial reuse and/or disposal (as appropriate) of an estimated 9,000 cy of sediments.
- Dredging an estimated 20,000 to 30,000 cy (including overdredge allowances) of wood chips and sediments from the northern area of the SMA where TVS exceeds 15 percent and sediments are inshore of -20 feet MLLW.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site.
- Beneficial reuse and/or upland disposal for material determined unsuitable for DMMP open-water disposal.
- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint and previously dredged area.
- Placing a nominal 2-foot-thick post-excavation backfill over the intertidal excavation footprint.
- Placing a nominal 4-foot-thick cap over areas exceeding 15 percent TVS that are not dredged, (i.e., areas offshore of -20 feet MLLW).
- Placing a nominal 6-inch-thick clean cover for EMNR over the remainder of the SMA.
- Implementing institutional controls for the area where caps are used. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 1 year (3 months of in-water work, Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-8 presents the conceptual Dredge, Cap, and EMNR alternative in SMA-2.

Cap Alternative Description

The Cap alternative focuses on containment of sediments in SMA-2. Limited excavation of the intertidal area is assumed so as to accommodate a cap in this area without modifying the location of the ordinary high water line. As with the Dredge and Cap alternatives, this alternative includes the additional overlay of the 2007 Interim Action being addressed with a nominal 6-inch-thick cover of clean EMNR sediment. The Cap alternative in SMA-2 entails the following major elements:

- Demolition and removal of creosoted structures and all creosoted piles as practicable, or cut off to a depth of 2 feet below the sediment surface, in SMA-2.
- Intertidal excavation and upland beneficial reuse and/or disposal (as appropriate) of an estimated 9,000 cy of sediments.
- Placing a nominal 2-foot-thick post-excavation backfill over the intertidal excavation footprint.
- Placing a nominal 4-foot-thick cap over areas that exceed TVS criteria.
- Placing a nominal 6-inch-thick clean cover for EMNR over the 2007 Interim Action footprint.
- Placing a nominal 1-foot-thick cap over the remainder of the SMA.
- Implementing institutional controls for the area where caps are used. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 3 months (Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-9 presents the conceptual Cap alternative in SMA-2.

Cap and EMNR Alternative Description

The Cap and EMNR alternative provides focused containment in TVS exceedance areas, and supplements this action with EMNR to accelerate recovery in the remaining area of the SMA, as well as the 2007 Interim Action area. The Cap and EMNR alternative in SMA-2 entails the following specific elements:

- Demolition and removal of creosoted structures and all creosoted piles as practicable, or cut off to a depth of 2 feet below the sediment surface, in SMA-2.
- Intertidal excavation and upland beneficial reuse and/or disposal (as appropriate) of an estimated 9,000 cy of sediments.
- Placing a nominal 2-foot-thick post-excavation backfill over the intertidal excavation footprint.
- Placing a nominal 4-foot-thick cap over areas that exceed 15 percent TVS.
- Placing a nominal 6-inch-thick clean cover for EMNR over the remainder of the SMA, including the 2007 Interim Action footprint.
- Implementing institutional controls for the area where caps are used. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 3 months (Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-10 presents the conceptual Cap and EMNR alternative in SMA-2.

Central Bay (SMA-3)

The Central Bay SMA (SMA-3) is a 77-acre area in the south-central bay that is characterized by surface sediment samples that exceed SQS criteria based on bioassay testing, contains somewhat elevated concentrations of wood waste breakdown products, and also exceeds criteria for protection of human health. A range of alternatives, including dredging, capping, EMNR, and MNR were evaluated for this SMA.

Dredge Alternative Description

Dredging in SMA-3 entails removal of an assumed 2-foot-thick surface layer of sediment, with a 1-foot allowable overdepth. The specific activities included in the FS for this alternative include:

- Dredging an estimated 375,000 to 560,000 cy (including overdredge allowances) of surface sediment across the SMA.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site. The percentage of SMA-3 dredge material potentially "suitable" for open-water disposal is not known, as this material has not been screened against DMMP criteria. However, the FS assumes that 50 percent of SMA-3 dredge material could potentially be suitable for open-water disposal, with the remaining unsuitable material disposed off-site in an upland landfill.
- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint.
- Performing compliance monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 4 to 5 years (Table 6-3), considering the anticipated in-water construction windows that are typically required for marine construction projects, which would require significant stretches of time (February 15 to November 15, based on past experience in this area) when in-water construction would not be allowed. This equates to dredging approximately 100,000 cy of material per season, which is within the range of demonstrated production on other large-scale Puget Sound remedial dredging projects. Figure 6-11 presents the conceptual Dredge alternative for SMA-3.

Cap Alternative Description

Capping in SMA-3 entails placement of an assumed 1-foot-thick surface layer of clean sand to contain sediments within the 77-acre footprint. The specific activities included in the FS for this alternative include:

- Procuring and placing 180,000 to 200,000 tons of clean beneficial reuse sand to cap the SMA footprint.

- Implementing institutional controls for the cap area. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 1 year (3 months of in-water construction, Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-12 presents the conceptual Cap alternative footprint for SMA-3.

EMNR Alternative Description

The EMNR alternative in SMA-3 entails placement of a nominal 6-inch-thick surface layer of clean sand to accelerate the recovery of sediments within the 77-acre SMA footprint. The specific activities included in the FS for this alternative include:

- Procuring and placing 90,000 to 100,000 tons of clean beneficial reuse sand for EMNR cover within the SMA.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 2 months (Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-13 presents the conceptual EMNR alternative footprint for SMA-3.

MNR Alternative Description

The MNR remedy in SMA-3 does not entail active construction. Rather, MNR would consist of a series of sediment monitoring events at a scope and frequency defined in the CAP to verify the anticipated continued recovery of the benthic community and reduction of concentrations of bioaccumulative chemicals of concern to the site-specific cleanup standards due to natural processes (sedimentation, bioturbation, and biodegradation). Similar to the EMNR alternative, long-term monitoring would be performed at 5- to 10-year intervals over a 20- to 30-year period (with more extensive sampling and analysis at approximately $50,000 per event), and would be defined in more detail in the CAP. If the MNR alternative were selected, the CAP would include clear endpoints and timeframes for measuring success and triggers for initiating more active alternatives if recovery is not occurring in a reasonable timeframe.

Former Lease Area (SMA-4)

The FLA (SMA-4) includes approximately 19.1 acres of Port Gamble Bay adjacent to the western shoreline near the south end of the Site. This area is characterized by SQS bioassay exceedances, elevated levels of wood waste breakdown products, and bioaccumulative contaminants above human health-based cleanup standards (Ecology 2012). A range of alternatives, including dredging, capping, EMNR, and MNR were evaluated for this SMA.

Dredge Alternative Description

Dredging in SMA-4 entails removal of an assumed 2-foot-thick surface layer of sediment, with a 1-foot allowable overdepth. The specific activities included in the FS for this alternative include:

- Removal of creosoted pilings throughout the entire SMA.
- Dredging an estimated 90,000 to 140,000 cy (including overdredge allowances) of surface sediment across the SMA.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site. The percentage of SMA-4 dredge material potentially "suitable" for open-water disposal is not known, as this material has not been screened against DMMP criteria. However, the FS assumes that 50 percent of SMA-4 dredge material would potentially be suitable for open-water disposal, with the remaining unsuitable material disposed off-site in an upland landfill.
- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint.
- Performing compliance monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 2 years (Table 6-3), considering the anticipated in-water construction windows that are typically required for marine construction projects, which would require significant stretches of time

(February 15 to November 15, based on past experience in this area) when in-water construction would not be allowed. Figure 6-14 presents the conceptual Dredge alternative for SMA-4.

Cap Alternative Description

Capping in SMA-4 entails placement of an assumed 1-foot-thick surface layer of clean sand to contain sediments within the 19-acre footprint. The specific activities included in the FS for this alternative include:

- Removal of creosoted pilings throughout the entire SMA.
- Procuring and placing 45,000 to 50,000 tons of clean beneficial reuse sand to cap the SMA footprint.
- Implementing institutional controls for the cap area. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 1 month (Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-15 presents the conceptual Cap alternative footprint for SMA-4.

EMNR Alternative Description

The EMNR alternative in SMA-4 entails placement of a nominal 6-inch-thick surface layer of clean sand to accelerate the recovery of sediments within the 19-acre SMA footprint. The specific activities included in the FS for this alternative include:

- Removal of creosoted pilings throughout the entire SMA.
- Procuring and placing 20,000 to 25,000 tons of clean beneficial reuse sand for EMNR cover within the SMA.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 1 month (Table 6-3). Figure 6-16 presents the conceptual EMNR alternative footprint for SMA-4.

MNR Alternative Description

As in the Central Bay SMA (SMA-3), the MNR remedy in SMA-4 does not entail active construction beyond removal of creosoted pilings throughout the entire SMA, but consists of a series of sediment monitoring events at a scope and frequency defined in the CAP, as described above. The MNR alternative would include clear endpoints and timeframes for measuring success and triggers for initiating more active alternatives if recovery is not occurring in a reasonable timeframe.

cPAH Background Area (SMA-5)

The cPAH Background Area (SMA-5) includes sediments exceeding site-specific cleanup standards based on natural background or PQLs for cPAHs, dioxins/furans, and cadmium in the bay. This SMA surrounds and includes all of the other SMAs, and thus also serves as the Site boundary for sediments. SMA-5 has a total area of 602 acres, not including the areas associated with SMA-1 through SMA-4.

Because the evidence of current biological impacts in SMA-5 is relatively limited, widespread use of technologies such as dredging or engineered containment, which would remove or place a thick sequence of sand over recovering sediments and functioning habitat, respectively, would lead to unnecessary disruptions of the biological communities present in SMA-5. Thus, the Dredge, Cap, and EMNR alternatives were retained for a subset of this SMA: those areas of the SMA where surface sediment concentrations exceed site-specific cleanup levels by at least a factor of 3. The surface area of this portion of SMA-5 is approximately 196 acres. However, as a source control measure for protection of human health, the creosoted pilings that remain throughout the entire SMA will be removed under each of the alternatives below.

Dredge Alternative Description

Dredging in SMA-5 entails removal of an assumed 2-foot-thick surface layer of sediment, with a 1-foot allowable overdepth in the 196-acre area described above. The specific activities included in the FS for this alternative include:

- Removal of creosoted pilings and structures throughout the entire SMA. The majority of piles in this SMA are associated with the FLTF dock, and the log rafting piles offshore of this dock.
- Dredging an estimated 900,000 to 1,400,000 cy (including overdredge allowances) of surface sediment across a subset of the SMA.
- Screening and removal of debris for upland disposal.
- Transport and disposal of suitable dredge material at a non-dispersive DMMP open-water disposal site. The percentage of SMA-5 dredge material potentially "suitable" for open-water disposal is not known, as this material has not been screened against DMMP criteria. However, the FS assumes that 50 percent of SMA-5 dredge material would potentially be suitable for open-water disposal, with the remaining unsuitable material disposed off-site in an upland landfill.
- Placing a nominal 6-inch-thick post-dredge residuals cover over the dredge footprint.
- Performing long-term monitoring to assess the effectiveness of this remedy and recovery of the impacted benthic community.

The estimated construction duration of this remedial alternative is approximately 10 to 15 years (Table 6-3), considering the anticipated in-water construction windows that are typically required for marine construction projects, which would require significant stretches of time (February 15 to November 15, based on past experience in this area) when in-water construction would not be allowed. Figure 6-17 presents the conceptual Dredge alternative for SMA-5.

Cap Alternative Description

Capping in SMA-5 entails placement of an assumed 1-foot-thick surface layer of clean sand to contain sediments within the 196-acre footprint. The specific activities included in the FS for this alternative include:

- Removal of creosoted pilings and structures throughout the entire SMA.
- Procuring and placing 475,000 to 500,000 tons of clean beneficial reuse sand to cap the subset of the SMA footprint identified.

- Implementing institutional controls for the cap area. Institutional controls would, at a minimum, include a site use and deed restriction.
- Performing long-term monitoring to assess the effectiveness of this remedy and recovery of the impacted benthic community.

The estimated construction duration of this remedial alternative is approximately 3 years (Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-18 presents the conceptual Cap alternative footprint for SMA-5.

EMNR Alternative Description

The EMNR alternative in SMA-5 entails placement of a nominal 6-inch-thick surface layer of clean sand to accelerate the recovery of sediments within the 196-acre SMA footprint. The specific activities included in the FS for this alternative include:

- Removal of creosoted pilings and structures throughout the entire SMA.
- Procuring and placing 225,000 to 250,000 tons of clean beneficial reuse sand for EMNR cover within the SMA.
- Performing long-term monitoring to assess the effectiveness of this remedy.

The estimated construction duration of this remedial alternative is approximately 1 to 2 years (Table 6-3) provided that a sufficient supply of sand can be procured over this time frame. Figure 6-19 presents the conceptual EMNR alternative footprint for SMA-5.

MNR Alternative Description

As in the Central Bay (SMA-3) and FLA (SMA-4) SMAs, the MNR remedy in SMA-5 does not entail active construction beyond removal of creosoted pilings throughout the entire SMA, but consists of a series of sediment monitoring events at a scope and frequency defined in the CAP. The MNR alternative would include clear endpoints and timeframes for measuring success and triggers for initiating more active alternatives if recovery is not occurring in a reasonable timeframe.

Detailed Evaluation and Comparison of Marine Alternatives

This section provides a narrative description of the evaluation and comparison of these alternatives for each SMA. In each description, an absolute numeric ranking is provided ranging from 1 to 5, where 1 is the lowest (least favorable) ranking and 5 is the highest (most favorable) ranking. These absolute rankings are ultimately modified by weighting factors (discussed in Section 5.2) when summed to the total score for each alternative. Table 6-1 summarizes the evaluation and tabulates the overall score for each alternative. Table 6-2 provides a summary of estimated costs, and Table 6-3 summarizes estimated volumes and durations associated with each alternative.

Mill Site North (SMA-1) Detailed Evaluation

Threshold Evaluation

All of the alternatives evaluated for SMA-1 meet the SMS threshold criteria of protection of human health and the environment, and attainment of cleanup standards. Each alternative has been configured to meet the required cleanup standards, and all alternatives will meet the cleanup standard within a 10-year time frame. Finally, cleanup will be achieved in compliance with applicable laws.

Short-term Effectiveness

For the Dredge alternative, short-term effectiveness was given a score of 3 for human health and 4 for environment, for an average score of 3.5. This scoring reflects the relatively large volume of material that needs to be handled in this alternative and potential risks to human health associated with this work, as well as generated dredge residuals.

For the Dredge and Cap alternative, less material is removed, with less attendant human health risk during implementation. At the same time, dredge residuals will still result in environmental impact. Thus, this alternative was given a score of 4 for human health, and 4 for environment, for an average score of 4.0.

The Cap alternative does not require upland management of dredge material and debris, and thus represents the lowest potential risk to human health. However, there are water quality impacts associated with placing a large volume of capping material, which represents a short-term environmental risk. Thus, this alternative ranks 5 for human health, and 4 for environment, for an overall average of 4.5.

The Cap and EMNR alternative entails handling the lowest volume of material, and thus has the lowest attendant risks to both human health and the environment. This alternative scored 5 for both human health and the environment, for an overall average score of 5.0.

Long-term Effectiveness

The long-term effectiveness of the Dredge alternative ranks high for protection of human health and the environment because source material is removed to the maximum extent practicable. Because of generated dredge residuals, this alternative ranks marginally lower for certainty and reliability, and residual risks. This alternative was scored 5 for human health, 5 for environment, 4 for certainty/reliability, and 4 for residual risks, for an average score of 4.5.

The Dredge and Cap alternative has a similar ranking to the Dredge alternative; however, the residual risk category ranks lower because of the reliance on caps to prevent exposure to material that remains in the environment. Thus, the scoring is 5, 5, 4, 3 for human health, environment, certainty/reliability, and residual risk, respectively, for an overall average of 4.3.

The Cap alternative is protective of human health because the exposure pathway to sediments is removed; a score of 5 was assigned. Because the benthic community will reside within the cap matrix and there remains a lower risk of toxicity due to sulfides from decomposing wood waste (though the caps would be designed to address this risk), environment ranks slightly lower compared to human health, and was scored 4. Because institutional controls are required, capping has lower certainty/reliability compared to removal, and was scored 3. Similar to the Dredge and Cap alternative, residual risk was also scored 3, for an overall average score of 3.8 for long-term effectiveness.

The Cap and EMNR alternative is similar to the Cap alternative and ranks 5 for protection of human health. However, the reliance on EMNR in parts of the SMA results in a lower score of 3 for environment because of the potential for benthic exposure before natural recovery processes have reduced concentrations below criteria. EMNR presumes ongoing natural recovery following placement of clean sand, and thus is less certain (until a demonstration is made through long-term monitoring) than capping, so certainty has been scored 2. Similarly, residual risk ranks 2 because of the reliance on EMNR in portions of the SMA. The overall average score for long-term protectiveness is 3.0 for the Cap and EMNR alternative.

Implementability

The technical feasibility of the Dredge alternative was given a score of 4 in consideration of the amount of material handled, and the need to process debris and unsuitable dredge material in an available upland location. Materials and equipment for dredging are commonly available, and this criterion was scored 5. Finally, dredging projects are routinely permitted in Puget Sound and have the support of regulatory agencies when performed in conjunction with cleanup, and thus this criterion scored 5. The overall average implementability score for the Dredge alternative is 4.8.

The Dredge and Cap alternative is the same as the Dredge alternative from an implementability standpoint, and the same considerations and scoring are applied. The implementability average score for this alternative is also 4.8.

Capping ranks higher for technical feasibility compared to dredging because there would be less need for upland sorting or processing of excavated material. Thus, the Cap alternative was scored 5 for technical feasibility. Capping materials and equipment are commonly available, and thus this criterion was also scored 5. Finally, as with dredging, there is regulatory and permitting support for capping performed during environmental cleanup, and this criterion scored 5 as well, for an overall average score of 5.0 for implementability.

The Cap and EMNR alternative has the same considerations as the Cap alternative and was thus scored the same, with an overall average score of 5.0.

Cost

The Dredge alternative in SMA-1 has the highest estimated cost ($1.1 million/acre) and the lowest rank, scoring 1. The Dredge and Cap alternative is estimated to cost $900,000/acre and has a score of 2. The Cap and Cap and EMNR alternatives are estimated to cost $700,000/acre, and have been given a score of 3 for cost. Table 6-2 provides a summary of the estimated costs for all of the alternatives. Appendix A provides details for the cost estimates.

Community Concerns

As this is one of the smaller SMAs with relatively few existing shellfish beds that would be impacted by the cleanup, a stronger preference has been expressed for removal (dredging) of as much material as possible. Removal of contaminated sediments also provides the greatest flexibility for future land uses in this area. This preference is reflected in a score of 5 for the Dredge alternative, a score of 3 for the Dredge and Cap alternative, and scores of 1 for the Cap and EMNR alternatives.

Recycling and Waste Minimization

The ability for a sediment cleanup project to use recycling and waste minimization is limited to a few key opportunities discussed in Section 5. The Dredge alternative has limited opportunity for recycling or reuse, while at the same time generating waste during excavation, and was thus scored 2. The Dredge and Cap, Cap, and Cap and EMNR alternatives have the potential to beneficially reuse navigationally dredged sand for cap material, and thus all of these alternatives were scored 3 for this evaluation criterion.

Environmental Impacts

The potential environmental impacts associated with all alternatives rank equally considering that the scale and scope of each project is similar. The environmental impacts associated with dredge residuals are relatively low due to the relatively low volume of material excavated. The environmental (water quality) impacts associated with cap material placement are also relatively low considering the relatively low volume of material used. Thus, all alternatives were scored 4 for consideration of environmental impacts.

Preferred Alternative

Based on this evaluation, the Dredge and Cap, Cap, and Cap and EMNR total scores rank highest. The Dredge and Cap alternative was identified by Ecology as the preferred alternative among these three due to Ecology's preference for removal of dense wood waste deposits as part of the remedy, particularly in areas with identified sulfide toxicity.

The restoration timeframe for the Dredge and Cap alternative is approximately 2 to 3 years for design, permitting, and implementation.

Mill Site South (SMA-2) Detailed Evaluation

Threshold Evaluation

The Dredge alternative meets the threshold criteria for protection of human health and the environment, and achieves cleanup standards within a 10-year time frame. However, a Dredge alternative over this large area is likely to have significant water quality impacts that would be difficult to control. There are also concerns about resuspension and distribution of wood debris and contaminated sediments to other areas of the bay. For these reasons, this alternative may be more difficult to obtain permits for, and it may also be more difficult to remain in compliance with water quality limits during implementation.

The remaining alternatives evaluated for SMA-2 meet the SMS threshold criteria of protection of human health and the environment, and attainment of cleanup standards. Each of these alternatives has been configured to meet the required cleanup standards, and all of the remaining alternatives will meet the cleanup standard within the required 10-year time frame. Finally, cleanup will be achieved in compliance with applicable laws.

Short-term Effectiveness

For the Dredge alternative, short-term effectiveness was given a score of 1 for human health and 1 for environment, for an average score of 1.0. This scoring reflects the significant volume of material that needs to be handled in this alternative, resulting in significant potential risks to human health associated with this work based on documented health and safety issues that show measurable increased worker safety risk for marine construction compared to upland construction. The large volume of dredge material would also result in significant generated dredge residuals and unknown residual distribution and impacts on the rest of the bay.

For the Dredge and Cap alternative, less material is removed than the Dredge alternative, with less attendant human health risk during implementation. However, the overall volume of removal is still significant. Further, significant generated dredge residuals will result in environmental impact. Thus, this alternative was given a score of 2 for human health, and 1 for environment, for an average score of 1.5.

The Dredge and Cap II alternative removes less volume than the Dredge and Cap alternative. Considerations about human health and the environment are similar, but scoring is higher to reflect the lower removal volume, with a value of 3 selected for human health, and 2 for environment, for an overall average score of 2.5.

The Dredge, Cap, and EMNR alternative balances removal and capping such that the dredging is focused on the highest concentration of woody debris in the area most susceptible to porewater sulfide generation. The result is a lower volume of removal compared to the Dredge and Cap II alternative, and a greater percentage of the dredged material would be suitable for open-water disposal. The dredge prism is also located in an area that is less subject to strong currents. Because of the lower risks associated with the lower volume of removal, human health and environment both score 4, with an overall average of 4.0 for this alternative.

The Cap alternative requires limited upland management of dredge material and debris (from the intertidal excavation area), and thus represents the lowest potential risk to human health. While there may be water quality impacts associated with placing a large volume of capping material, this represents a short-term environmental risk that is lower than the risk of water quality impacts and residuals generation associated with removal. Thus, this alternative ranks 5 for human health, and 5 for environment, for an overall average of 5.0.

The Cap and EMNR alternative entails handling the lowest volume of material, and thus has the lowest attendant risks to both human health and the environment. This alternative scored 5 for both human health and the environment, for an overall average score of 5.0.

Long-term Effectiveness

The long-term effectiveness of the Dredge alternative ranks high for protection of human health and the environment because source material is removed to the maximum extent practicable. Because of generated dredge residuals, this alternative ranks marginally lower for certainty and reliability, and residual risks. This alternative was scored 5 for human health, 5 for environment, 4 for certainty/reliability, and 4 for residual risks, for an average score of 4.5.

The Dredge and Cap alternative has a similar ranking to the Dredge alternative; however, the residual risk category ranks lower because of the reliance on caps to maintain protectiveness. Thus, the scoring is 5, 5, 4, 3 for human health, environment, certainty/reliability, and residual risk, respectively, for an overall average of 4.3.

The Dredge and Cap II alternative has a similar ranking to the Dredge and Cap alternative; however, the environment category ranks slightly lower because less removal is accomplished. Thus, the scoring is 5, 4, 4, 3 for human health, environment, certainty/ reliability, and residual risk, respectively, for an overall average of 4.0.

The Dredge, Cap, and EMNR alternative shares the same considerations and scoring as the Dredge and Cap II alternative, and thus has an overall average score of 4.0 for long-term effectiveness.

The Cap alternative is protective of human health because the exposure pathway to sediments is removed; a score of 5 was assigned. Because the benthic community (and in particular, geoducks) will reside within the cap matrix, environment ranks slightly lower compared to human health, and was scored 4. Because institutional controls are required and there may be a lower risk of continuing sulfides impacts (though the caps would be designed to address this risk), capping has lower certainty/reliability compared to removal, and was scored 3. Similar to the Dredge, Cap, and EMNR alternative, residual risk was also scored 3, for an overall average score of 3.8 for long-term effectiveness.

The Cap and EMNR alternative is similar to the Cap alternative and ranks 5 for protection of human health. However, the reliance on EMNR in parts of the SMA results in a lower score of 3 for environment because of the potential for benthic exposure before natural recovery processes have reduced concentrations below criteria. EMNR presumes ongoing natural recovery following placement of clean sand, and thus is less certain (until a demonstration is made through long-term monitoring) than capping, and thus certainty/reliability has been scored 2. Finally, residual risk ranks 1 because of the reliance on EMNR in portions of the SMA, and because of the risk posed by the relatively large volume of woody debris that remains under this alternative. The overall average score for long-term protectiveness is 2.8 for the Cap and EMNR alternative.

Implementability

The technical feasibility of the Dredge alternative was given a score of 3 in consideration of the relatively large amount of material handled, and the need to process debris and unsuitable dredge material in an available upland location. While materials and equipment for dredging are commonly available, the upland space required for processing up to 100,000 to 150,000 cy (representing the 75 percent of SMA-2 material assumed to be unsuitable for DMMP open-water disposal) of dredge material is significant and the ability to manage this volume upland is questionable; thus this criterion was scored 2. The permitting and regulatory criterion was scored 4 because the large volume of dredging could trigger regulatory concerns. The overall average implementability score for the Dredge alternative is 3.0.

The Dredge and Cap alternative is similar to the Dredge alternative from an implementability standpoint, and the same considerations and scoring (3) are applied for technical feasibility. Because the volume of dredge material is lower, the scores for availability of materials and space, as well as the score for regulatory and permitting is slightly higher than the dredge alternative, with scores of 3 and 5, respectively. The implementability average score for the Dredge and Cap alternative is 3.8.

The Dredge and Cap II alternative entails a lower volume of material handled on the upland compared to the Dredge and Cap alternative, and thus has been assigned a higher score of 4 for technical feasibility. Considerations for availability of materials/space, and permitting/regulatory are reduced, and thus a score of 4 was assigned. Finally, a score of 5 was assigned for regulatory/permitting (similar to other small- to medium-scale dredging alternatives) for an overall average score of 4.3.

The Dredge, Cap, and EMNR alternative is similar in scope and scale to the Dredge and Cap alternative, and the scoring for implementability reflects this, with an overall average of 4.3 for this alternative.

Capping ranks higher for technical feasibility compared to dredging because there would be less need for upland sorting/processing of excavated material. Thus, the Cap alternative was scored 5 for technical feasibility. Capping materials and equipment are commonly available; however, a relatively large volume of cap material would be required under this alternative (over 100,000 tons), and thus this criterion was scored 4. Finally, as with dredging, there is regulatory and permitting support for capping performed during environmental cleanup, and this criterion scored 5 as well, for an overall average score of 4.8 for implementability.

The Cap and EMNR alternative has the same considerations as the Cap alternative and similar cap material volume requirements and was thus scored the same, with an overall average score of 4.8.

Cost

The Dredge alternative in SMA-2 has the highest estimated cost ($1.6 million/acre) and the lowest rank, scoring 1. The Dredge and Cap alternative is estimated to cost $1.1 million/acre and has also been assigned a score of 1. The Dredge and Cap II alternative is estimated to cost $900,000/acre and has been assigned a score of 2. The Dredge, Cap, and EMNR alternative has an estimated cost of $510,000/acre and has been assigned a score of 3. The Cap and Cap and EMNR alternatives are estimated to cost $370,000/acre, and have been given a score of 4 for cost, as summarized in Table 6-2.

Community Concerns

This SMA represents the area most heavily impacted by mill operations over time, and where it has been reported by divers that geoducks have been heavily impacted by wood wastes in sediments. While dredging large volumes of wood waste and impacted sediments may present some challenges and short-term risks to human health and the environment, the long-term gains over multiple generations from cleaning up this area have been stated by community and tribal members as being worth the risks. Therefore, like at SMA-1, alternatives that result in greater long-term removal (dredging) of contaminated sediments were scored higher. The Dredge alternative received a score of 5; the Dredge and Cap alternative a score of 4; Dredge and Cap II (which dredges lower quantities of sediments) a score of 3; Dredge, Cap, and EMNR a score of 2; and both the Cap and Cap and EMNR alternatives a score of 1.

Recycling and Waste Minimization

The ability for a sediment cleanup project to use recycling and waste minimization is limited to a few key opportunities discussed in Section 5. As with SMA-1, the Dredge alternative in SMA-2 has limited opportunity for recycling or reuse, while at the same time generating waste during excavation, and was thus scored 2.

The Dredge and Cap alternative has the potential to beneficially reuse sand for cap material, and thus this alternative was scored 3 for this evaluation criterion.

The Dredge and Cap II and Dredge, Cap, and EMNR alternatives are similar to the Dredge and Cap alternative, with the key difference that they would generate less waste from the removal process, and thus these alternatives were scored 4.

Finally, the Cap and Cap and EMNR alternatives produce the least waste and have the highest potential for recycling through the beneficial reuse of maintenance dredge material in the cap, and thus these alternatives both score 5 for this evaluation criterion.

Environmental Impacts

The potential environmental impacts associated the Dredge alternative are significant. The large volume of material removed (140,000 to 200,000 cy) and associated water quality and dredge residuals impacts would be substantial. Because open-water disposal would only be applicable to a small portion of the dredge material, upland rehandling would result in significant noise, traffic, and local air emissions at the offloading facility and during transloading to the landfill. Marine traffic associated with dredging would interfere with local fishing and shellfish harvest activities for at least 3 years, and noise and light associated with this long-term construction project would cause notable impacts on the local communities that surround Port Gamble Bay. As a result, the Dredge alternative was given a score of 1 for the environmental impacts criterion.

The Dredge and Cap and Dredge and Cap II alternatives have lower overall dredge volumes and lower impacts associated with dredging. There are additional potential water quality impacts (specifically turbidity) associated with cap material placement that are not associated with dredging, because the volume of material placed is higher under these alternatives than under the Dredge alternative. Thus, these two alternatives were both assigned a score of 3 for environmental impacts.

The Dredge, Cap, and EMNR alternative provides a balanced approach that minimizes impacts associated with dredging, and reduces impacts associated with capping compared to the Cap alternative. Thus, this alternative was assigned a score of 4.

The Cap alternative does not result in dredge-related impacts; however, this alternative does require placement of significant volumes of material for cap construction, and thus has been assigned a score of 3 for environmental impacts.

The Cap and EMNR alternative requires less cap material placement than the Cap alternative and, therefore, scores comparatively higher at 4 for environmental impacts.

Preferred Alternative

Based on this evaluation, the Dredge, Cap, and EMNR alternative and the Cap alternative total scores rank highest. The Dredge, Cap, and EMNR alternative was identified by Ecology as the preferred alternative due to Ecology's preference for removal of large deposits of wood waste as part of the remedy, particularly in areas with identified sulfide toxicity. However, the overall cost of the Dredge, Cap, and EMNR alternative presumes the use of open-water disposal for 50 percent of the dredge material, consistent with OPG/PR's preliminary screening-level sampling.

The restoration timeframe for the Dredge, Cap, and EMNR alternative is approximately 3 years for design, permitting, and implementation.

Central Bay (SMA-3) Detailed Evaluation

Threshold Evaluation

The Dredge alternative meets the threshold criteria for protection of human health and the environment, and achieves cleanup standards within a 10-year time frame. However, dredging over this large area is likely to have significant water quality impacts that would be difficult to control. There are also concerns about resuspension and distribution of wood debris and contaminated sediments to other areas of the bay. For these reasons, this alternative may be more difficult to obtain permits for, and it may also be more difficult to remain in compliance with water quality limits during implementation.

The Cap and EMNR alternatives for SMA-3 meet the SMS threshold criteria of protection of human health and the environment, and attainment of cleanup standards. Each of these alternatives has been configured to meet the required cleanup standards, and these alternatives will meet the cleanup standard within a 10-year time frame. Finally, cleanup will be achieved in compliance with applicable laws for the Cap and EMNR alternatives.

The MNR alternative does not meet the threshold criteria for protection of human health and the environment or attainment of cleanup standards/compliance with laws. Bioassay results currently exceed SQS, and cPAH levels are on the order of 2 to 4 times the cleanup level. Because ongoing natural recovery has not been documented in this SMA and sedimentation rates in the area are very low, this alternative is not expected to meet the cleanup standards within 10 years.

Short-term Effectiveness

For the Dredge alternative, short-term effectiveness was given a score of 1 for human health and 1 for environment, for an average score of 1.0. This scoring reflects the substantial volume of dredge material that needs to be managed in this alternative (with approximately twice the volume compared to the Mill Site South Dredge alternative—and similar effectiveness considerations on a larger scale), as well as generated dredge residuals, which will result in a significant environmental impact in the Central Bay.

The Cap alternative does not require upland management of dredge material and debris, and thus represents the lowest potential risk to human health. However, there are water quality impacts associated with placing a large volume of capping material, which represents a short-term environmental risk. Thus, this alternative ranks 5 for human health and 3 for environment, for an overall average of 4.0.

The EMNR alternative entails handling the lowest volume of material, and thus has the lowest attendant risks to both human health and the environment. This alternative scored 5 for both human health and the environment, for an overall average score of 5.0.

Because MNR does not take active measures to improve human health and the environment in the short term, it was scored 1 for both of these criteria, for an overall average of 1.0 for short-term effectiveness.

Long-term Effectiveness

The long-term effectiveness of the Dredge alternative ranks high for protection of human health and the environment because source material is removed to the maximum extent practicable. However, the scale of the removal would require more than eight construction seasons to complete, which significantly impacts the certainty that the dredging remedy can be completed. Finally, due to generated dredge residuals, this alternative ranks marginally lower for residual risks. This alternative was scored 5 for human health, 5 for environment, 2 for certainty/reliability, and 4 for residual risks, for an average score of 4.0.

The Cap alternative is protective of human health because the exposure pathway to sediments is removed; a score of 5 was assigned. Because the benthic community will reside within the cap matrix, environment ranks lower compared to human health, and was scored 4. Because institutional controls are required, capping has lower certainty/reliability compared to removal, and was scored 4. Similar to the Cap alternatives in the other SMAs, residual risk was also scored 3, for an overall average score of 4.0 for long-term effectiveness.

The EMNR alternative is similar to the Cap alternative and ranks 5 for protection of human health. However, the reliance on EMNR in parts of the SMA results in a lower score of 3 for environment because of the potential for benthic exposure before natural recovery processes have reduced concentrations below criteria. EMNR presumes ongoing natural recovery following placement of clean sand, and thus is less certain than capping; however, bioassay exceedances are very close to the SQS and so it is reasonable to assume EMNR can be reliable in reducing toxicity to the benthic community. Thus certainty/reliability has been scored 4. Residual risk ranks 2 because of the reliance on natural recovery processes and the fact that material is not removed under this alternative. The overall average score for long-term protectiveness is 3.5 for the EMNR alternative.

The FS presumes that natural recovery is occurring very slowly in SMA-3, and thus MNR has been assigned a score of 1 for protection of human health and 2 for protection of the environment because the predominant issue in the Central Bay is exceedance of cPAH levels. Further, MNR is scored 1 for certainty/reliability and 1 for residual risks because active measures are not taken under this alternative. The overall average score for long-term effectiveness of MNR in SMA-3 is 1.3.

Implementability

The technical feasibility of the Dredge alternative was given a score of 2 in consideration of the significant amount of material handled, and the need to process debris and unsuitable dredge material in an available upland location. Materials and equipment for dredging are commonly available; however, the space required to manage 200,000 to 250,000 cy of dredge material would likely be difficult, if not impossible to find, and thus this criterion was scored 1. Finally, while dredging projects in Puget Sound typically have the support of regulatory agencies when performed in conjunction with cleanup, it is expected that dredging on the scale necessary in SMA-3 for this alternative would create significant concerns, and thus this criterion scored 2. The overall average implementability score for the Dredge alternative is 1.8.

Capping ranks higher for technical feasibility compared to dredging because there would be less need for upland sorting/processing of excavated material. Thus, the Cap alternative was scored 4 for technical feasibility. While capping equipment is commonly available, procuring more than 180,000 tons of cap material for this alternative could be difficult, and thus this criterion was scored 3. Finally, there is typically regulatory and permitting support for capping performed during environmental cleanup, and this criterion was scored 5, for an overall average score of 4.0 for implementability.

The EMNR alternative has similar considerations to the Cap alternative but ranks higher for technical feasibility and availability of materials because only one-half of the cap material is required under this alternative. Thus, scores were 5, 4, and 5 for technical feasibility, availability of materials and equipment, and permitting/regulatory considerations, respectively, for an overall average score of 4.8.

MNR does not entail active construction. Implementability is related to periodic sampling during each monitoring event. Because it does not trigger any of the technical feasibility, materials availability, or permitting/regulatory issues that occur with active construction, all factors were assigned a score of 5, for an overall average score of 5.0 for implementability.

Cost

The Dredge alternative in SMA-3 has the highest estimated cost ($800,000/acre) and the lowest rank, scoring 2. The Cap alternative is estimated to cost $60,000/acre and has been assigned a score of 5. The EMNR alternative is estimated to cost $40,000/acre and has been given a score of 5 for cost. MNR is estimated to cost $5,000/acre in the Central Bay and has been assigned a score of 5. Table 6-2 provides a summary of the estimated cost for all of the alternatives in SMA-3, with details provided in Appendix A.

Community Concerns

The Central Bay is a much larger area than those at the mill site, and contains thriving geoduck beds that serve as a recruitment area for the commercial beds to the north. This SMA is also in the center of the bay and both dredging and capping actions will interfere with fishing over the short-term. Balancing these considerations is the need to clean up an area of the bay in which breakdown products of wood waste have settled and formed flocculant sediments that are undesirable habitat for shellfish, fish, crab, and other biota. Therefore, alternatives received a higher score that would have the potential to improve sediment conditions for biota and remediate contamination while still allowing survival of the existing benthic community and interfering with fishing activities as little as possible.

Based on these considerations, the Dredge alternative received a score of 2. This alternative would require 7 years of dredging operations in the center of the bay, and would likely resuspend a great deal of flocculant sediments that would settle elsewhere in the bay. In addition, dredging would destroy the existing geoduck beds and benthic community throughout this area. The Cap alternative received a score of 3. This alternative would have fewer impacts than the Dredge alternative and would require only two capping seasons to carry out. However, the full 1-foot cap envisioned under this alternative would likely kill the existing benthic community, including the geoduck bed, which would require a substantial period of time to become reestablished. The EMNR alternative is similar, but uses a 6-inch layer of sediments, which would likely be enough to improve the physical and chemical conditions in sediments without completely eliminating the shellfish and benthic communities. The MNR alternative received a score of 1, because it does not result in any immediate benefit to this area and public comments were received expressing clear dissatisfaction with this approach in the bay.

Recycling and Waste Minimization

Similar to SMA-1 and SMA-2, the Dredge alternative in SMA-3 has limited opportunity for recycling or reuse, while at the same time generating waste during excavation, and was thus scored 2 for recycling/waste minimization.

The Cap alternative and the EMNR alternative produce the least waste and have the highest potential for recycling through the beneficial reuse of maintenance dredge material in the cap, and thus these alternatives both score 5 for this evaluation criterion.

MNR does not entail active construction. There is no opportunity for recycling or waste minimization with this alternative. MNR has been assigned a score of 1 for this criterion.

Environmental Impacts

The potential environmental impacts associated the Dredge alternative are significant. Dredging over 4 to 8 years would have substantial community impact, with noise, air, and light issues affecting the Port Gamble Bay community, disruption of access to fishing and shellfish harvesting, and significant potential air emissions associated with the marine equipment and offloading/transloading activity for the estimated more than 200,000 cy of material that would not be suitable for DMMP open-water disposal. The large volume of material removed, associated water quality and dredge residuals impacts, and community impacts described above result in a score of 1 for this criterion. In addition, dredging would eliminate the benthic community and any shellfish resources in the area remediated.

The Cap alternative does not result in dredge-related impacts; however, this alternative does require placement of significant volumes of material for cap construction, with associated potential for water quality impacts. This alternative also buries the benthic community. Although most elements of the benthic community recover within 2 to 3 years, larger organisms such as geoduck may require long timeframes for recovery. Thus, this alternative has been assigned a score of 2 for environmental impacts.

The EMNR alternative requires less and thinner cap material placement than the Cap alternative and, therefore, scores comparatively higher at 3 for environmental impacts.

Because MNR does not entail construction activities, there are no environmental impacts associated with this alternative. MNR has been assigned a score of 5 for environmental impacts.

Preferred Alternative

Based on this evaluation, the Cap alternative and EMNR alternative total scores rank similarly, with EMNR ranking highest of the alternatives. Thus, EMNR is the preferred alternative for SMA-3.

The restoration timeframe for the EMNR alternative is approximately 2 to 3 years for design, permitting, and implementation.

Former Lease Area (SMA-4) Detailed Evaluation

Threshold Evaluation

The Dredge, Cap, and EMNR alternatives for SMA-4 meet the SMS threshold criteria of protection of human health and the environment, and attainment of cleanup standards. Each of these alternatives has been configured to meet the required cleanup standards, and these alternatives will meet the cleanup standard within a 10-year time frame. Finally, cleanup will be achieved in compliance with applicable laws for the Dredge, Cap, and EMNR alternatives.

The MNR alternative does not meet the threshold criteria for protection of human health and the environment or attainment of cleanup standards/compliance with laws. Bioassay results currently exceed SQS, and cPAH levels are on the order of 2 times the cleanup level. Because ongoing natural recovery has not been documented in this SMA, and sedimentation rates in the area are very low, this alternative is not expected to meet the cleanup standards within 10 years.

Short-term Effectiveness

For the Dredge alternative, short-term effectiveness was given a score of 1 for human health and 1 for environment, for an average score of 1.0. This scoring reflects the large volume of dredge material that needs to be managed in this alternative and potential risks to human health associated with this work, as well as generated dredge residuals in a more nearshore shellfish-rich environment, which may result in a significant environmental impact in the FLA.

The Cap alternative does not require upland management of dredge material and debris, and thus represents the lowest potential risk to human health. However, there are water quality impacts associated with placing the capping material, which represents a short-term environmental risk. Thus, this alternative ranks 5 for human health and 4 for environment, for an overall average of 4.5.

The EMNR alternative entails handling the lowest volume of material, and thus has the lowest attendant risks to both human health and the environment. This alternative scored 5 for both human health and the environment, for an overall average score of 5.0.

Because MNR does not take active measures to improve human health and the environment in the short term, it was scored 1 for both of these criteria, for an overall average of 1.0 for short-term effectiveness.

Long-term Effectiveness

The long-term effectiveness of the Dredge alternative ranks high for protection of human health and the environment because source material is removed to the maximum extent practicable. The ability to dredge a site of this size has been demonstrated on other projects, and the overall duration is reasonable, making dredging rank high for certainty/reliability. Finally, due to generated dredge residuals, this alternative ranks marginally lower for residual risks. This alternative was scored 5 for human health, 5 for environment, 5 for certainty/reliability, and 4 for residual risks, for an average score of 4.8.

The Cap alternative is protective of human health because the exposure pathway to sediments is removed; a score of 5 was assigned. Because the benthic community will reside within the cap matrix, environment ranks lower compared to human health, and was scored

4. Although institutional controls are required, capping can be completed in a reasonable time frame, and thus certainty/reliability was scored 5. Similar to the Cap alternatives in the other SMAs, residual risk was also scored 3, for an overall average score of 4.3 for long-term effectiveness.

The EMNR alternative is similar to the Cap alternative and ranks 5 for protection of human health. However, the reliance on EMNR in parts of the SMA results in a lower score of 4 for environment because of the potential for benthic exposure before natural recovery processes have reduced concentrations below criteria. EMNR presumes ongoing natural recovery following placement of clean sand, and thus is less certain than capping. Thus, certainty/reliability has been scored 4. Residual risk ranks 3 because of the reliance on natural recovery processes and the fact that material is not removed under this alternative. The overall average score for long-term protectiveness is 4.0 for the EMNR alternative.

Similar to the Central Bay SMA, the FS presumes that natural recovery is occurring very slowly in SMA-4, and thus MNR has been assigned a score of 1 for protection of human health and 2 for protection of the environment. Further, MNR is scored 1 for certainty/reliability and 1 for residual risks because active measures are not taken under this alternative. The overall average score for long-term effectiveness of MNR in SMA-4 is 1.3.

Implementability

The technical feasibility of the Dredge alternative was given a score of 3 in consideration of the large volume of material handled, and the need to process debris and unsuitable dredge material in an available upland location. Materials and equipment for dredging are commonly available; however, the space required to manage 50,000 to 60,000 cy of dredge material would be significant, and thus this criterion was scored 3. Finally, as with other alternatives, dredging cleanup projects of this scale in Puget Sound typically have the support of regulatory agencies, and thus this criterion scored 5. The overall average implementability score for the Dredge alternative is 3.8.

Capping ranks higher for technical feasibility compared to dredging because there would be less need for upland sorting/processing of excavated material. Thus, the Cap alternative was scored 4 for technical feasibility. Capping equipment is commonly available, and procuring the required volume of cap material for this alternative is feasible, and thus this criterion was scored 5. Finally, there is typically regulatory and permitting support for capping performed during environmental cleanup, and this criterion was scored 5, for an overall average score of 4.8 for implementability.

The EMNR alternative has similar considerations to the Cap alternative but ranks higher for technical feasibility and availability of materials because only one-half of the cap material is required under this alternative. Thus, scores were 5, 5, and 5 for technical feasibility, availability of materials and equipment, and permitting/regulatory considerations, respectively, for an overall average score of 5.0.

MNR does not entail active construction. Implementability is related to periodic sampling during each monitoring event. Because it does not trigger any of the technical feasibility, materials availability, or permitting/regulatory issues that occur with active construction, all factors were assigned a score of 5, for an overall average score of 5.0 for implementability.

Cost

The Dredge alternative in SMA-4 has the highest estimated cost ($800,000/acre) and the lowest rank, scoring 2. The Cap alternative is estimated to cost $100,000/acre and has been assigned a score of 5. The EMNR alternative is estimated to cost $70,000/acre and has been given a score of 5 for cost. MNR is estimated to cost $10,000/acre in the FLA and has been assigned a score of 5. Table 6-2 provides a summary of the estimated cost for all of the alternatives in SMA-4, with details provided in Appendix A.

Community Concerns

This SMA is also relatively small, and is located along a sloped area where neither substantial intertidal shellfish beds nor major geoduck beds are likely to be impacted by cleanup operations. It is also out of the way of most fishing activities in the bay. Therefore, based on preferences expressed by the community, alternatives that actively remove or remediate sediments in this SMA received higher scores. The Dredge and Cap alternatives both received a score of 4, the EMNR alternative received a score of 3, and the MNR alternative received a score of 1.

Recycling and Waste Minimization

Similar to the other SMAs, the Dredge alternative in SMA-4 has limited opportunity for recycling or reuse, while at the same time generating waste during excavation, and was thus scored 2 for recycling/waste minimization.

The Cap alternative and the EMNR alternative produce the least waste and have the highest potential for recycling through the beneficial reuse of maintenance dredge material in the cap, and thus these alternatives both score 5 for this evaluation criterion.

MNR does not entail active construction. There is no opportunity for recycling or waste minimization with this alternative. MNR has been assigned a score of 1 for this criterion.

Environmental Impacts

The potential environmental impacts associated the Dredge alternative are greater than for capping alternatives. The relatively large volume of material removed and associated water quality and dredge residuals impacts result in a score of 3 for this criterion.

The Cap and EMNR alternatives do not result in dredge-related impacts; however, these alternatives do require placement of relatively large volumes of material during construction, with associated potential for water quality impacts, and thus both of these alternatives have been assigned a score of 4 for environmental impacts.

Because MNR does not entail construction activities, there are no environmental impacts associated with this alternative. MNR has been assigned a score of 5 for environmental impacts.

Preferred Alternative

Based on this evaluation, the Cap alternative and EMNR alternative total scores rank similarly, with EMNR ranking highest of the alternatives. Thus, EMNR is the preferred alternative for SMA-4.

The restoration timeframe for the EMNR alternative is approximately 2 years for design, permitting, and implementation.

cPAH Background Area (SMA-5) Detailed Evaluation

Threshold Evaluation

None of the alternatives for SMA-5 meet the SMS threshold criteria of protection of human health and, therefore, none meet the requirement for attainment of cleanup standards. Consistent with SMS, because no practicable alternative exists to achieve cleanup levels, a technical practicability evaluation is necessary for SMA-5. This evaluation is described in Section 6.4.

Although active measures cannot achieve risk-based cleanup levels, four alternatives were carried through the SMS detailed evaluation as described subsequently: Dredge and MNR, Cap and MNR, EMNR and MNR, and MNR. The active remedies focus on a subset of the SMA where concentrations exceed 3 times cleanup levels. Thus, each of the alternatives also has an MNR component for those areas of the SMA between 1 and 3 times the cleanup level.

Short-term Effectiveness

For the Dredge and MNR alternative, short-term effectiveness was given a score of 1 for human health and 1 for environment, for an average score of 1.0. This scoring reflects the substantially large volume of dredge material (an estimated 1.0 to 1.4 million cy) that needs to be managed in this alternative and potential risks to human health associated with this work, as well as generated dredge residuals, which will result in a significant environmental impact in the bay. In addition, the benthic community and existing geoduck beds would be impacted over 196 acres of the bay, which is a substantial percentage of the resources present. Only some of these resources would be expected to recover within a few years.

The Cap and MNR alternative does not require upland management of dredge material and debris, and thus represents a lower potential risk to human health compared to dredging. However, there are water quality impacts associated with placing the capping material, and potential bay-wide concerns with the scale of material placement (approximately 500,000 tons of cap material) under this alternative, which represent a short-term human health and environmental risk. As above, the benthic community and existing geoduck beds would be impacted over 196 acres of the bay, which is a substantial percentage of the resources present. Thus, this alternative ranks 2 for human health and 2 for environment, for an overall average of 2.0.

The EMNR and MNR alternative entails handling the lowest volume of material, and thus has the lowest attendant risks to both human health and the environment. However, the scale of material placement is still significant, with more than 200,000 tons of material needed. This alternative scored 2 for both human health and 3 for environment (indicating the possibility that some of the benthic community may survive a thinner layer placement), for an overall average score of 2.5.

Because MNR does not take active measures to improve human health in the short term, it was scored 1 for this criterion. On the other hand, the concentrations of chemicals in SMA-5 do not present a risk to the benthic community, and so this MNR is scored 5 for short-term environmental impact, for an overall average of 3.0 for short-term effectiveness.

Long-term Effectiveness

The long-term effectiveness of the Dredge and MNR alternative ranks low for protection of human health because much of the bay remains unaddressed even after implementing the remedial action. Dredging ranks medium for long-term environment effectiveness; while the SMA-5 primary COC, cPAH, is not a benthic risk driver, the Dredge and MNR alternative would still disrupt significant portions of the benthic community, and long-term geoduck impacts could be expected. Dredging on this scale has not been demonstrated locally, and the overall duration is significant, making dredging rank low for certainty/reliability. Finally, due to generated dredge residuals, this alternative ranks marginally lower for residual risks. This alternative was scored 2 for human health, 3 for environment, 2 for certainty/reliability, and 4 for residual risks, for an average score of 2.8.

The Cap and MNR alternative ranks low for protection of human health because much of the SMA is not remediated under this alternative; a score of 2 was assigned. Although cPAH are not a benthic risk driver, placement of approximately 500,000 tons of sand for capping under this alternative could significantly disrupt the geoduck community; thus long-term effectiveness for the environment was scored 3. Institutional controls would be required, and capping would require more than 3 years to complete; thus, certainty/reliability was scored 3. Similar to the Cap alternatives in the other SMAs, residual risk was also scored 3, for an overall average score of 2.8 for long-term effectiveness.

The EMNR and MNR alternative is similar to the Cap alternative and ranks 2 for protection of human health. However, because this alternative entails placement of a nominal 6-inch-thick cover, the benthic community would be expected to be only marginally disrupted and thus a score of 4 was used for protection of the environment. EMNR presumes ongoing natural recovery following placement of clean sand, and thus is less certain than capping. Thus certainty/reliability has been scored 2. Residual risk ranks 2 because of the reliance on natural recovery processes and the fact that material is not removed under this alternative. The overall average score for long-term protectiveness is 2.5 for the EMNR and MNR alternative.

Similar to the Central Bay SMA, the FS presumes that natural recovery is occurring very slowly in SMA-5, and thus MNR has been assigned a score of 1 for protection of human health and 5 for protection of the environment. Further, MNR is scored 1 for certainty/reliability and 1 for residual risks because active measures are not taken under this alternative. The overall average score for long-term effectiveness of MNR in SMA-5 is 2.0.

Implementability

The technical feasibility of the Dredge and MNR alternative was given a score of 2 in consideration of the substantially large volume of material handled, and the need to process debris and unsuitable dredge material in an available upland location, which would present a logistical challenge for a project of this scale. Materials and equipment for dredging are commonly available; however, the space required to manage 500,000 to 700,000 cy of dredge material (the 50 percent of dredge material assumed unsuitable for DMMP open-water disposal) would be significant, if not impossible to find, and thus this criterion was scored 1. Finally, while dredging projects in Puget Sound typically have the support of regulatory agencies when performed in conjunction with cleanup, it is expected that dredging on the scale necessary in SMA-5 for this alternative would create significant concerns, and thus this criterion scored 2. The overall average implementability score for the Dredge and MNR alternative is 1.8.

Capping ranks higher for technical feasibility compared to dredging because there would be less need for upland sorting/processing of excavated material. Thus, the Cap and MNR alternative was scored 3 for technical feasibility. Capping equipment is commonly available; however, procuring almost 500,000 tons of cap material for this alternative could be very difficult, and thus this criterion was scored 2. Finally, there is typically regulatory and permitting support for capping performed during environmental cleanup; however, the volume of material and logistics required to obtain this material are significant and thus this criterion was scored 4, for an overall average score of 3.0 for implementability.

The EMNR and MNR alternative has similar considerations to the Cap alternative but ranks higher for technical feasibility and availability of materials because only one-half of the cap material is required under this alternative. Thus, scores were 4, 3, and 5 for technical feasibility, availability of materials and equipment, and permitting/regulatory considerations, respectively, for an overall average score of 4.0.

MNR does not entail active construction. Implementability is related to periodic sampling during each monitoring event. Because it does not trigger any of the technical feasibility, materials availability, or permitting/regulatory issues that occur with active construction, all factors were assigned a score of 5, for an overall average score of 5.0 for implementability.

Cost

The Dredge and MNR alternative in SMA-5 has the highest estimated cost ($800,000/acre) and the lowest rank, scoring 2. The Cap and MNR alternative is estimated to cost $60,000/acre and has been assigned a score of 5. The EMNR and MNR alternative is estimated to cost $30,000/acre and has been given a score of 5 for cost. MNR is estimated to cost $2,000/acre in SMA-5 and has been assigned a score of 5. Table 6-2 provides a summary of the estimated cost for all of the alternatives in SMA-5, with details provided in Appendix A.

Community Concerns

For this SMA, there are few practicable alternatives, and it was not considered likely that any of them would fully address community concerns for the larger bay. Active cleanup alternatives such as dredging and capping would have major impacts on the ecological health of the bay, as well as fisheries activities, and dredging would also create a great deal of resuspension throughout the bay that could temporarily increase contaminant concentrations in seafood as well as impact a variety of biological resources due to turbidity. On the other hand, allowing the bay to naturally recover will be a lengthy process.

Reflecting these issues, all of the scores for this SMA were low. The Dredge and MNR alternative was given a score of 1 due to its major detrimental ecological impacts on the bay, as well as interference with fisheries operations over a period of 18 years. The Cap and MNR and the EMNR and MNR alternatives would also have significant impacts on the bay and interference with fisheries, and were given a score of 2. MNR was given a score of 1, as it does not provide immediate improvements in the bay in areas that are not included in other SMAs.

Recycling and Waste Minimization

Similar to the other SMAs, the Dredge and MNR alternative in SMA-5 has limited opportunity for recycling or reuse, while at the same time generating waste during excavation, and was thus scored 2 for recycling/waste minimization.

The Cap and MNR alternative and the EMNR and MNR alternative produce the least waste and have the highest potential for recycling through the beneficial reuse of maintenance dredge material in the cap, and thus these alternatives both score 5 for this evaluation criterion.

MNR does not entail active construction. There is no opportunity for recycling or waste minimization with this alternative. MNR has been assigned a score of 1 for this criterion.

Environmental Impacts

The potential environmental impacts associated the Dredge and MNR alternative are significant. As with the Mill Site South and Central Bay dredging alternatives, community impacts during construction of a cPAH Background Dredge and MNR remedy (air quality, noise, light, and traffic) would be substantial and over a long duration. Impacts to bay users (tribal and recreational fishing, shellfish harvesting, etc.) would mean significant disruption and interference in the use of this resource for 10 or more years. The substantially large volume of material removed and associated water quality and dredge residuals impacts, as well as the community impacts result in a score of 1 for this criterion.

The Cap and MNR alternative does not result in dredge-related impacts; however, this alternative does require placement of significant volumes of material for cap construction, with associated potential for water quality impacts, and related interference with the use of Port Gamble Bay for fishing and shellfish harvest during construction, and thus has been assigned a score of 2 for environmental impacts.

The EMNR and MNR alternative requires less cap material placement than the Cap alternative and, therefore, scores comparatively higher at 3 for environmental impacts.

Because MNR does not entail construction activities, there are no environmental impacts associated with this alternative. MNR has been assigned a score of 5 for environmental impacts.

Preferred Alternative

Although none of the alternatives meet threshold requirements, based on this evaluation, the Cap and MNR alternative, EMNR and MNR alternative, and MNR alternative total scores rank similarly. Because of the substantially higher costs associated with capping and EMNR compared to MNR, the minimal additional benefit provided, and the possibility for harm to resources in the bay, the MNR alternative was identified by Ecology as the preferred alternative for SMA-5.

The restoration timeframe for the MNR alternative is unknown, but expected to be greater than 10 years.

Data Gaps Evaluation

During development of the FS alternatives, several data gaps were identified. This section describes those data gaps and provides a preliminary plan for addressing these data gaps during development of the CAP, and/or during remedial design as appropriate.

Mill Site Open-water Disposal Suitability

A portion of the dredge sediments generated from Mill Site North and Mill Site South are prospectively considered suitable for open-water disposal at a non-dispersive, unconfined DMMP open-water disposal site. Provided that large wood debris is appropriately screened, chemistry levels (including dioxin/furan) pass suitability criteria, and DMMP bioassays also pass suitability criteria, it is expected that the DMMP agencies would permit some or all of the SMA-1 and/or SMA-2 wood debris to be disposed in a suitable open-water disposal location.

The use of open-water disposal for dredge material is evaluated on a case-by-case basis, and future suitability determinations can be subject to evolving policy issues related to sediment chemistry. Prior to the FS, Mill Site North sediments underwent a preliminary screening that suggests these sediments would pass the open-water disposal suitability determination, including for dioxins/furans. Mill Site South sediments were screened against DMMP criteria as part of preliminary sampling recently performed by OPG/PR. Thus, in developing alternatives and associated costs, it has been assumed that 80 percent of Mill Site North and

25 percent of most of the Mill Site South sediments would be suitable for open-water disposal. Under the preferred SMA-2 Dredge, Cap, and EMNR alternative, approximately 50 percent of the sediments dredged from this SMA would be suitable for open-water disposal.

Additional characterization of these sediments would be required to confirm the use of open-water disposal. Sampling and characterization in accordance with DMMP protocols would need to formally occur for specific areas identified in SMA-1 and SMA-2 depending on the proposed dredge area. Formal DMMP suitability would be assessed during detailed design.

Vertical Extent of Wood Waste in Mill Site South (SMA-2)

The current understanding of the vertical extent of wood waste in the Mill Site South SMA is limited to key core locations where the contact between wood waste and native sediments was directly observed. In contrast to Mill Site North, prior geophysical data collection in Mill Site South was not as clearly consistent with the coring observations of the contact with wood waste. Thus, the required bottom elevation of a proposed dredge prism in SMA-2 is less certain, and additional data collection through coring during remedial design will allow the horizontal and vertical extents of dredging to be refined for SMA-2. Because the preferred SMA-2 Dredge, Cap, and EMNR alternative focuses dredging inshore of -20 feet MLLW, less data collection would be necessary to design this remedy, compared to the other SMA-2 alternatives that include a dredging component.

Natural Recovery Trends

There is a limited bioassay dataset for documenting natural recovery trends. In the absence of sufficient bioassay data to demonstrate a trend in recovery, an approach using multiple lines of evidence (for example, net sedimentation measurements, hydrodynamic modeling, bioassay and chemical concentration trends, etc.) has been used for other regional sediment feasibility studies. While a similar approach could be useful for addressing this data gap, ultimately the long-term trend in bioassay test results will be used for monitoring and cleanup decision-making.

Ideally, additional bioassay data and chemistry data for bioaccumulative chemicals would be collected in the future to compare to the most recent dataset provided in the RI, and trends in natural recovery assessed using these new data. For cleanup projects that require multiple years to implement, there may be an opportunity to collect future data, depending on when EMNR material becomes available for this area, to evaluate natural recovery trends and facilitate adaptive management decisions. Additional discussion of adaptive management opportunities is provided in Section 7.

Technical Practicability Evaluation for Background Area (SMA-5)

Introduction

The Background Area (SMA-5) is characterized by sediments and tissue cPAH concentrations that exceed human health risk criteria. As discussed in the RI, the natural background sediment and tissue cPAH concentrations also exceed MTCA risk criteria for protection of human health under the exposure scenarios modeled. However, cPAH concentrations in Site sediments exceed natural background by an order of magnitude.

Ecology selected a cleanup level for cPAHs based on the sediment background threshold value (BTV). BTVs are higher than natural background because they represent a 90 percent confidence interval on the 90th percentile background value. The cleanup level for cPAH was thus selected to be 16 μg/kg.

SMS defines the term "practicable" as "able to be completed in consideration of environmental effects, technical feasibility and cost." (WAC 173-204-200(19)). The general response actions of dredging, capping, and EMNR are technically impracticable in SMA-5. Given the scope and size of the SMA, environmental impacts from in-water construction on this scale (dredge residuals, water quality impacts during removal and material placement, impacts to shellfish beds, vessel and vehicle traffic, interference with fisheries, construction noise and light, and air emissions) would be substantial as discussed below, and Site use would be restricted for long periods of time during remedy implementation. More importantly, however, is that the best outcome that could be anticipated from an active remedy is that only about 30 percent of this SMA could be cleaned up to a natural background surface sediment concentration, which itself is higher than risk-based concentrations. Further, upon completion of a dredge, cap, or EMNR action in SMA-5, it is not clear that changes in tissue concentrations would be observable, and they would likely be very small compared to the overall risk.

The following details describe the environmental and community impacts that render dredging, capping, and EMNR impracticable for SMA-5.

Dredging Resuspension and Residuals Impacts

As previously discussed, dredging resuspension and residuals releases have been well-documented and would be expected to result in significant impacts to Port Gamble Bay if a dredging remedy were to be implemented in SMA-5. Based on bottom conditions in the bay, residuals loss on the order of 2 to 5 percent of the contaminant mass dredged would be expected (Bridges et al. 2008). For the 500,000 to 700,000 cy of dredging that would be conducted in SMA-5, this translates to a residual loss on the order of 15,000 to 50,000 tons of material. Dredging also unavoidably destroys the existing benthic community within the dredge footprint.

Potential risks posed by resuspension are discussed in Bridges et al. (2008). Short-term risks from resuspension occur due to increased water column exposure of contaminants, and include direct toxicity to benthos, as well as potential increases in bioaccumulation. Long-term risks to benthos from resuspension occur due to a redistribution of the exposure field of contaminants to the benthic community following completion of dredging.

Capping and EMNR Turbidity Impacts

As has been well-documented on other sediment remediation projects, placement of silt, sand, and gravel under water results in a turbidity plume, even for materials with very low fines content. The magnitude of the turbidity plume is a function of the percent fines, the volume of material placed, and the settling velocity of the cap material. The spread of the plume will vary depending on the settling velocity of the material, as well as prevailing currents and wind during cap/EMNR placement. Because of the number of variables involved, predicting the spread of a turbidity plume during cap/EMNR requires a complicated modeling process.

Widespread turbidity can cause a variety of environmental impacts, including a reduction in light penetration (and reduced photosynthesis), and impacts to adult fish, as well as affecting normal development of bivalve eggs and larva. Although not directly quantifiable, these impacts could potentially be significant, and span a long duration for a capping or EMNR remedial action in SMA-5, which would require placement on the order of 250,000 to 500,000 tons of cap/cover material over a period of 1 to 3 years.

Community Impacts

Under any construction scenario for SMA-5, community impacts from noise, light, air emissions, and truck traffic would be significant. Off-site transport and disposal of the 500,000 to 700,000 cy of dredge material would require 50,000 to 70,000 dump truck trips through the Port Gamble community, or wherever else an offloading site would be located. Import of 250,000 to 500,000 tons of cover or cap material from a beneficial reuse source would entail, at a minimum, 100 large barge trips into the bay, but more likely on the order of 200 to 500 barge trips based on typical equipment available for a project of this nature, which would inhibit the use of the bay for fishing and/or shellfish harvesting for anywhere from 1 to 3 years during the construction season. Where an upland quarry is required for cap/cover material, 20,000 to 40,000 truck trips would be needed to deliver the material.

Besides the direct community impacts during construction, related indirect impacts such as infrastructure wear and tear (e.g., pavement damage) would require additional mitigation upon completion of the SMA-5 remedial action.

Technical Practicability Conclusions

Based on the environmental and community impacts, logistical considerations, and overall feasibility of conducting a large-scale remedy in the Port Gamble Bay community, dredging, capping, and EMNR remedies are technically impracticable in SMA-5. Environmental impacts from dredging resuspension/residuals and turbidity from capping and EMNR would be significant. Community impacts such as air emissions, noise, light, and general community disruption would also be substantial.

As with active remedial measures, natural recovery processes are expected to result in a reduction in Site-wide cPAH concentrations over time, particularly after cPAH sources such as creosoted piles are removed during the remedial action. Recovery of SMA-5 will be monitored over time under the MNR alternative.

ADDITIONAL CLEANUP CONSIDERATIONS

Modifications to the Recommended Cleanup Action Alternative

The preferred cleanup action alternatives for the Site are described in Section 6, pending resolution of data gaps for SMA-1 and SMA-2. Depending on the timing of data gap resolution and the results of some of the key screening evaluations (e.g., open-water disposal suitability), the CAP may incorporate modifications to the preferred alternatives identified in the FS, as appropriate.

Protection of Cultural Resources

A bay-wide cultural resources overview was developed for Port Gamble Bay to identify and map areas of known or possible historical, archaeological, and cultural resources within the project area. The overview was developed by a professional archaeologist for OPG, DNR, and the Port Gamble S'Klallam Tribe and provided specific steps to complete identification, evaluation, and protection of cultural resources that may be affected by the Site cleanup action. Information from the overview was considered in developing the recommended cleanup action alternative for the Site. Significantly, none of the alternatives evaluated in this FS were eliminated based on cultural resource considerations, because the actions that are proposed will occur in locations and at elevations (i.e., recent fill) that are not expected to coincide with the presence of cultural resources.

During the follow-on remedial design and permitting phase of the cleanup action, the implementing parties, in consultation with the Washington Department of Archaeology and Historic Preservation (DAHP) and the Port Gamble S'Klallam Tribe, will identify areas that may be affected by the cleanup action. These areas will include locations where cleanup-related disturbance may occur, including dredging areas, staging areas, transport routes, and mooring areas, as appropriate. More detailed cultural resource evaluations will be integrated with studies for the engineering design phase of the project.

The cleanup action selected by Ecology for the Site will also include appropriate compliance monitoring provisions during implementation of the action, consistent with Section 106 requirements of the National Historic Preservation Act (NHPA) and Washington State laws. Detailed compliance monitoring plans will be developed during the remedial design and permitting phase, consistent with regulatory requirements. Appropriate cultural resource work plans, including a cultural resources treatment plan and an inadvertent discovery plan, will be included in the engineering design reports.

Habitat Restoration Opportunities

Cleanup of Port Gamble Bay provides an opportunity to integrate habitat restoration. Ecology, in concert with various stakeholders, has identified several priority habitat restoration opportunities in the bay. To the extent that restoration can be combined with cleanup, a cost-effective, integrated project can achieve combined benefits for habitat.

Restoration projects agreed to by Ecology, OPG, and DNR include the following:

- **Riparian Enhancement.** The Mill Site currently does not provide a riparian corridor along the shoreline. Adding riparian planting in the shoreline buffer zone will provide restoration benefits and is compatible with all of the cleanup alternatives considered, provided that the riparian improvement occurs after the need for shoreline access during cleanup has ended.
- **Over-water Structure Removal.** Over-water structures, including derelict and active docks, provide undesirable shading. Creosoted structures will be removed as part of the cleanup, but credit for removing shading will be provided as part of the restoration package as appropriate, based on whether structure removal is permanent.
- **Eastern Wharf and Southeastern Mill Site Fill Removal.** Ecology performed a coastal geomorphological evaluation of the Mill Site and determined that the natural sediment supply to the bay is effectively diverted by the presence of Mill Site fill placed historically during site development. Restoration will include removal of fill along the eastern and southeastern shorelines of the Mill Site uplands to create a more naturally contoured and sloping beach that will support forage fish habitat and shellfish restoration. Removal of fill is compatible with cleanup and can serve to restore sediment transport processes more similar to historic conditions. Removal of upland fill can occur during the same construction phase as intertidal excavation (following demolition activities), and is expected to require similar equipment to that

which would be used for intertidal work, for an integrated approach to remediation and restoration in these areas.

- **Debris Removal.** Scattered intertidal debris has been documented along the western shoreline of the bay, particularly adjacent to the former landfills. Removal of this debris, and general cleanup and riparian improvements at the landfill sites, provide a habitat restoration opportunity and are expected to improve conditions for eelgrass in this area. Because the area of restoration identified by Ecology is outside of the SMA areas where active remediation will occur, this restoration opportunity is compatible with all of the alternatives considered.
- **Former Log Transfer Facility Dock and Derelict Vessel Removal.** Removal of the FLTF dock will reduce overwater shading on the western shoreline of Port Gamble Bay, and removal of the derelict sunken vessel in this area will restore the shoreline in this area. The FLTF dock and derelict vessel are located north of the FLA SMA; thus this removal work can be accomplished without impact to the remedial action in the FLA.
- **Olympia Oyster Bed and/or Eelgrass Restoration.** Scattered debris is present along the western shoreline of Port Gamble Bay, south of the Mill Site. Removal of this debris will function to restore oyster beds and/or eelgrass in these areas. As all of these locations are outside of the Mill Site South SMA, this work can be accomplished independently or in concert with cleanup work, with negligible expected impact to the cleanup.

Ultimately, habitat restoration will be determined by Ecology, DNR, and OPG and integrated into cleanup design and implementation as appropriate. Restoration projects will be presented in greater detail in a separate Restoration Plan.

Adaptive Management Opportunities

The FS assumes that cap, cover, and residuals management materials will largely be sourced from a beneficial reuse maintenance event when the appropriate grain size is available. Based on the historical availability of such materials, it is only on a periodic basis that large volumes of this type of material are dredged in Puget Sound. Alternatively, smaller volumes from local maintenance dredge projects (marinas, etc.) may be available in any given year. Thus, large-scale capping and EMNR may require several years to generate sufficient volume to complete the remedy.

There can be an advantage associated with phasing the project implementation, as it allows for an adaptive management strategy to be used during the cleanup process. Because implementation is expected to take several years, the opportunity exists to collect interim data to gauge the rate and success of natural recovery processes. At the same time, it is desirable to use any capping material that becomes available (whether small or large volumes), to avoid missing opportunities. Phasing can be accomplished in several ways:

1. Discrete cap or EMNR areas can be selected for completion in any given year, and all of the available beneficial reuse material generated during that year would be dedicated to the identified area. The advantage of this approach is that an entire area could be considered effectively "finished" and long-term monitoring could be initiated. The disadvantage of this approach is that other areas that cannot be completed in a given year would remain unaddressed until a future construction season.
2. Wide areas could be addressed, with a thinner placement of material in a series of lifts that are completed as material comes available. This approach would allow interim monitoring to occur to gauge the effectiveness of the remedy as it is implemented. It could be determined that the initial thinner lifts (similar to EMNR) within an area that may have been proposed for capping have sufficiently addressed benthic and human health risk, and the adaptive management approach could ultimately result in a different final remedy for that area. This approach would also cover a wider area with the available material, at least partially addressing exposure over a greater footprint. Finally, this approach would cause less benthic disturbance and short-term environmental impact, as the benthic community is less likely to be damaged with thinner lifts of material, which would allow the community time to adapt before the next placement of material. The disadvantage of this approach is that larger areas of

the site would remain “unfinished” until adaptive management endpoints are met and/or full placement of the design thickness of material is achieved.

The use of phasing and adaptive management will be further addressed in the forthcoming CAP.

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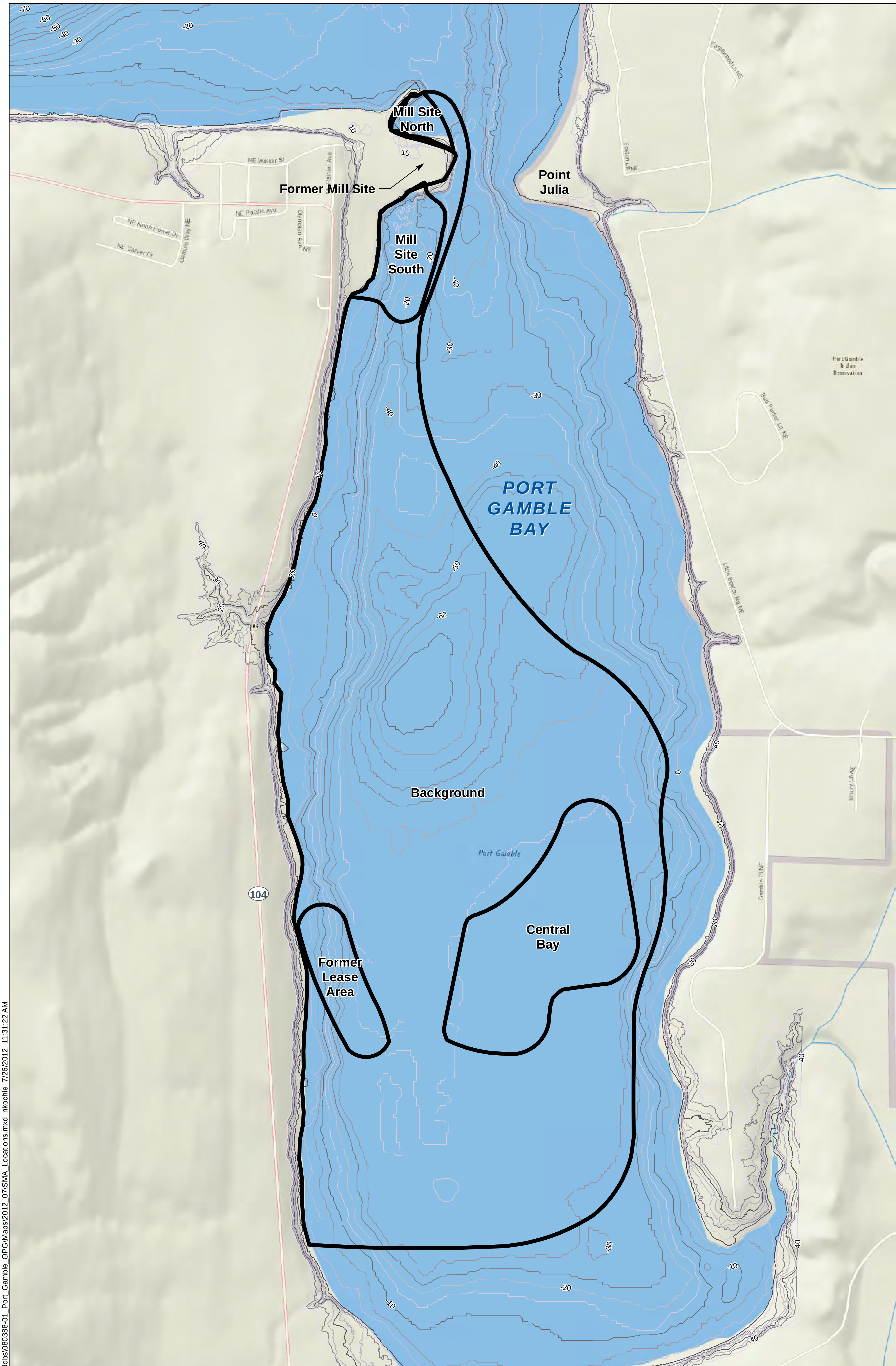
FIGURES



Port Gamble SMA

Topographic and Bathymetric Contour - 5-ft Intervals (MLLW Datum)

Feet
0 500 1,000 1,500 2,000

ANCHOR QEA

Figure 3-1
SMA Locations
Port Gamble Bay Feasibility Study

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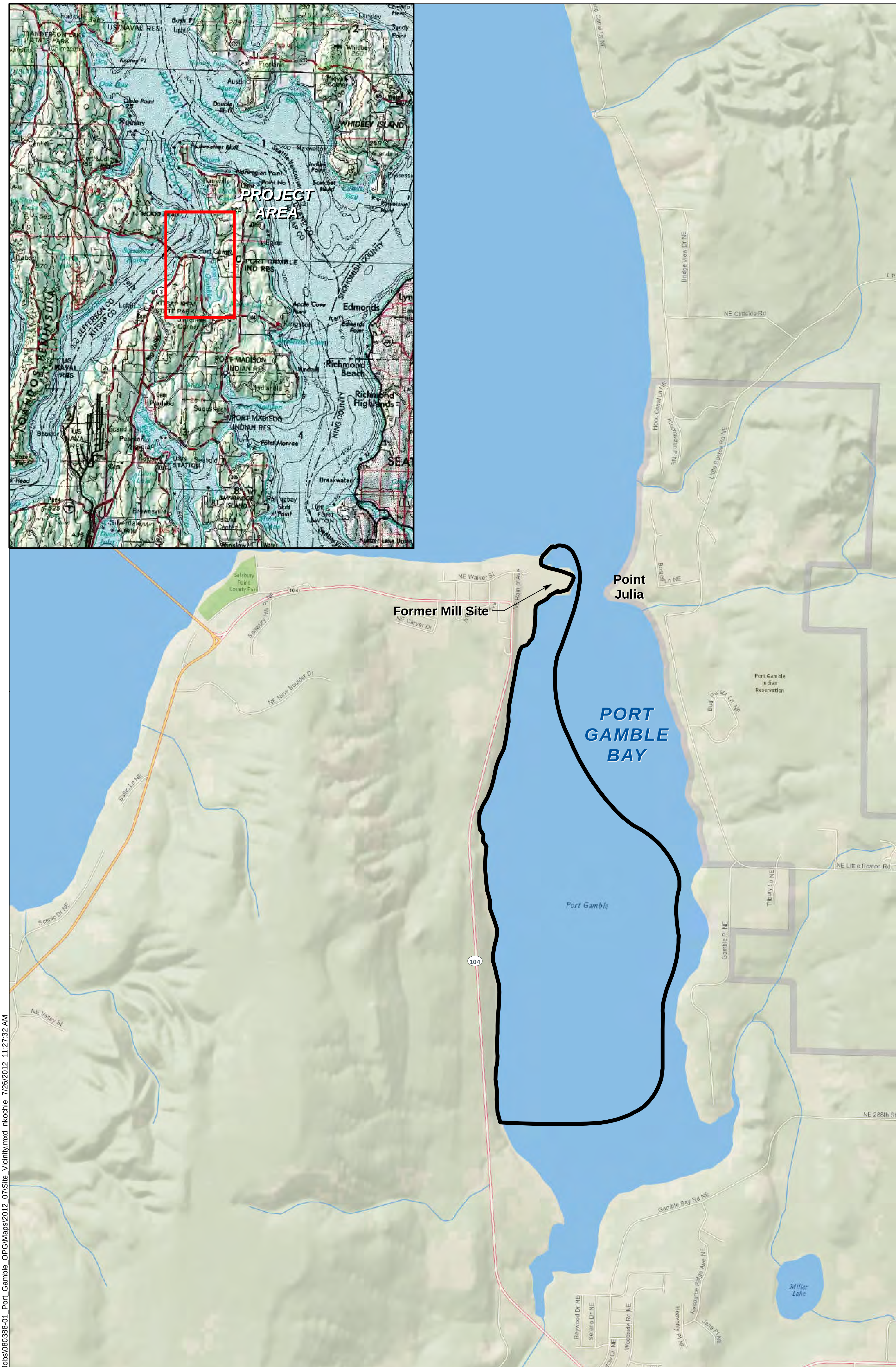

Feet
0 1,000 2,000 3,000 4,000

Site Boundary

Figure 1-1
Site Vicinity Map
Port Gamble Bay Feasibility Study

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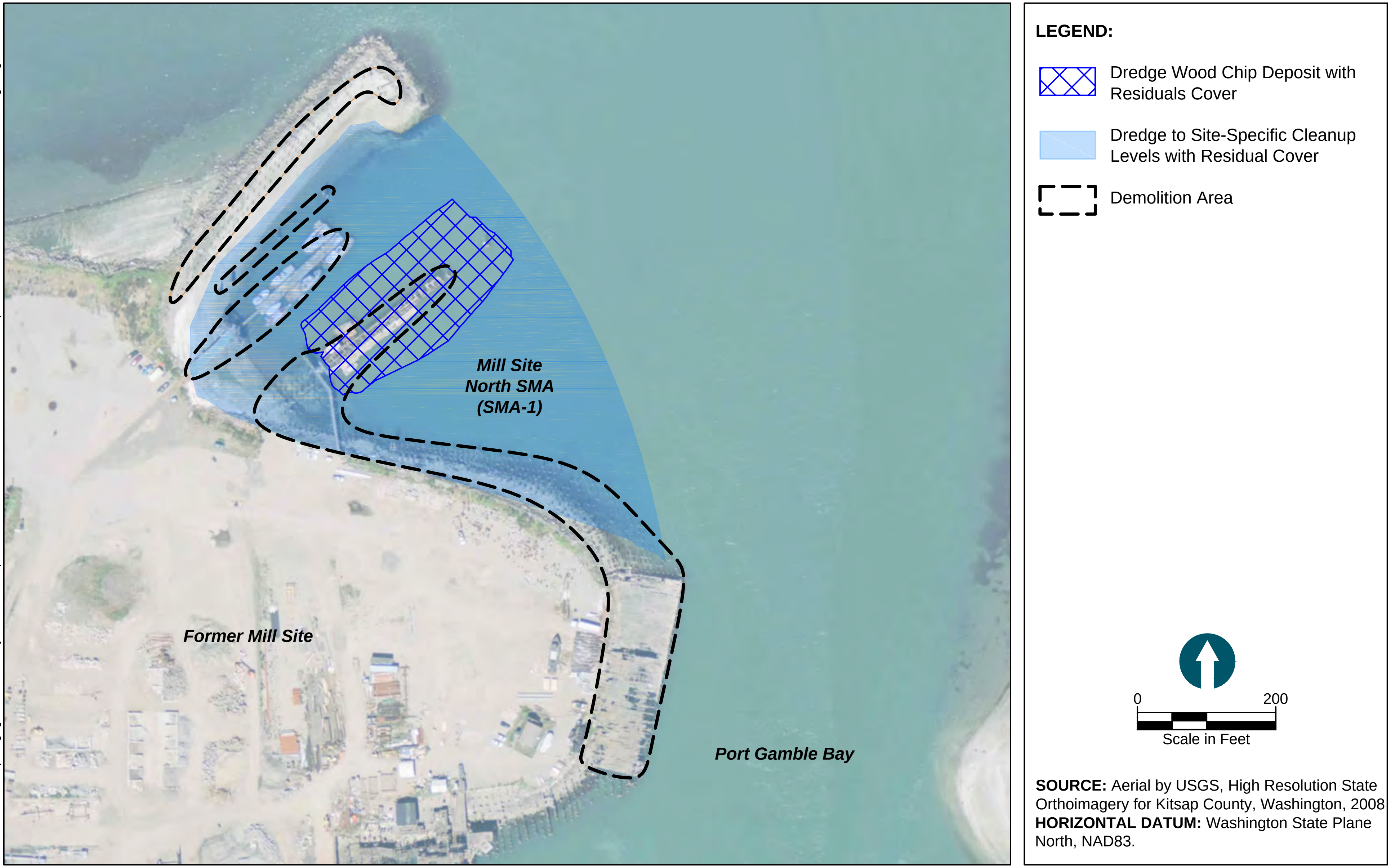

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Figure 6-1
MSN Dredge Alternative
Port Gamble Bay Feasability Study

LEGEND:

- Dredge Wood Chip Deposit with Residuals Cover
- Intertidal Cap
- Intertidal Cap Excavation
- 1-ft Thick Benthic Cap
- Demolition Area

0 200
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

Jul 25, 2012 4:45pm tgriga K:\Projects\0388-Pope Resources\Port Gamble Sediment Cleanup RI-FS\FS\0388-RP-FS Alternatives.dwg Figure 6-2

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Figure 6-2
MSN Dredge and Cap Alternative
Port Gamble Bay Feasability Study

LEGEND:

- Intertidal Cap
- Intertidal Cap Excavation
- 1-ft Thick Benthic Cap
- 4-ft Thick Benthic Cap
- Demolition Area

0 200
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

ANCHOR QEA

Figure 6-3
MSN Cap Alternative
Port Gamble Bay Feasability Study

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LEGEND:

- Intertidal Cap
- Intertidal Excavation
- 4-ft Thick Benthic Cap
- EMNR
- Demolition Area

0 200
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

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Figure 6-4
MSN Cap and EMNR Alternative
Port Gamble Bay Feasability Study

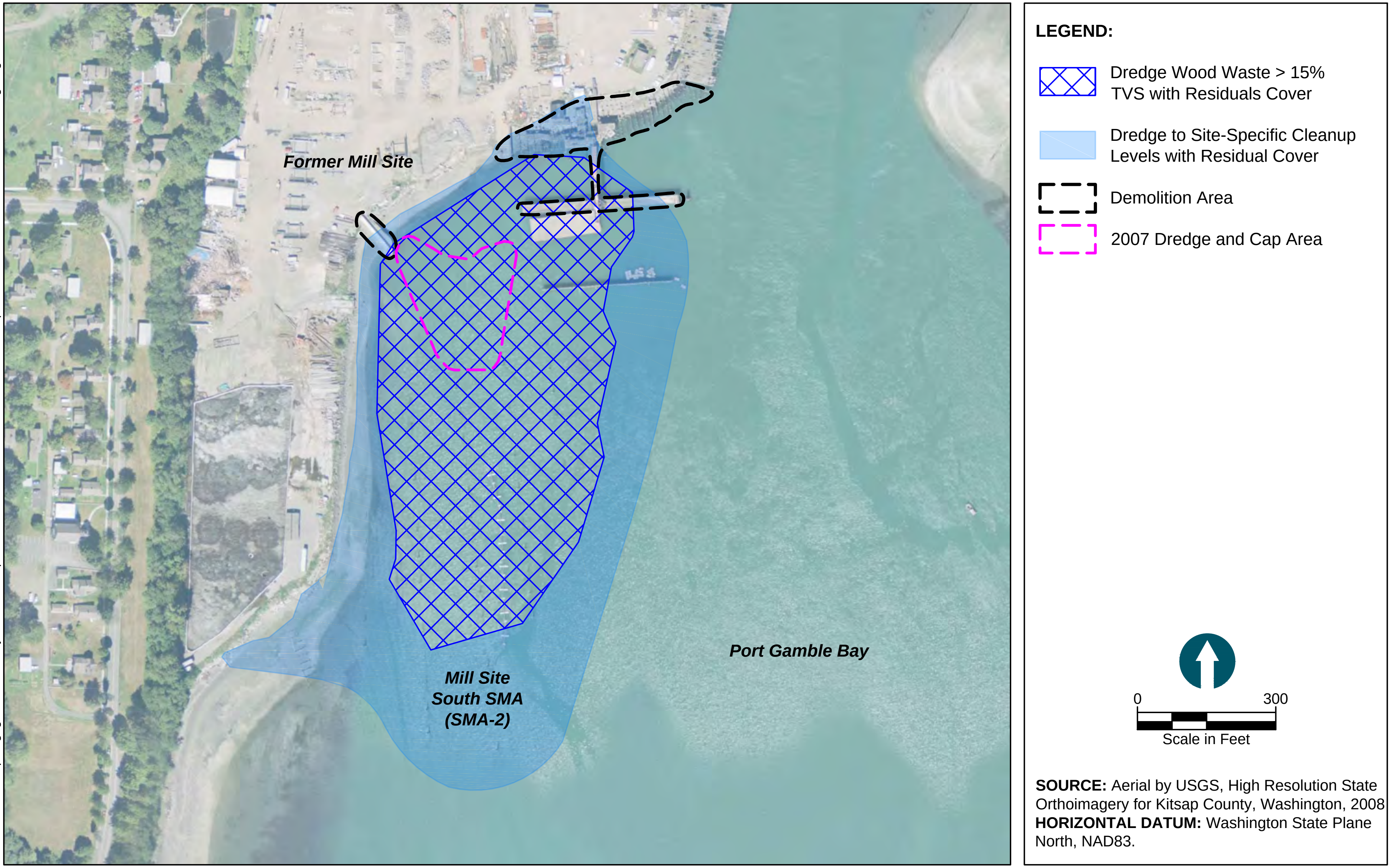

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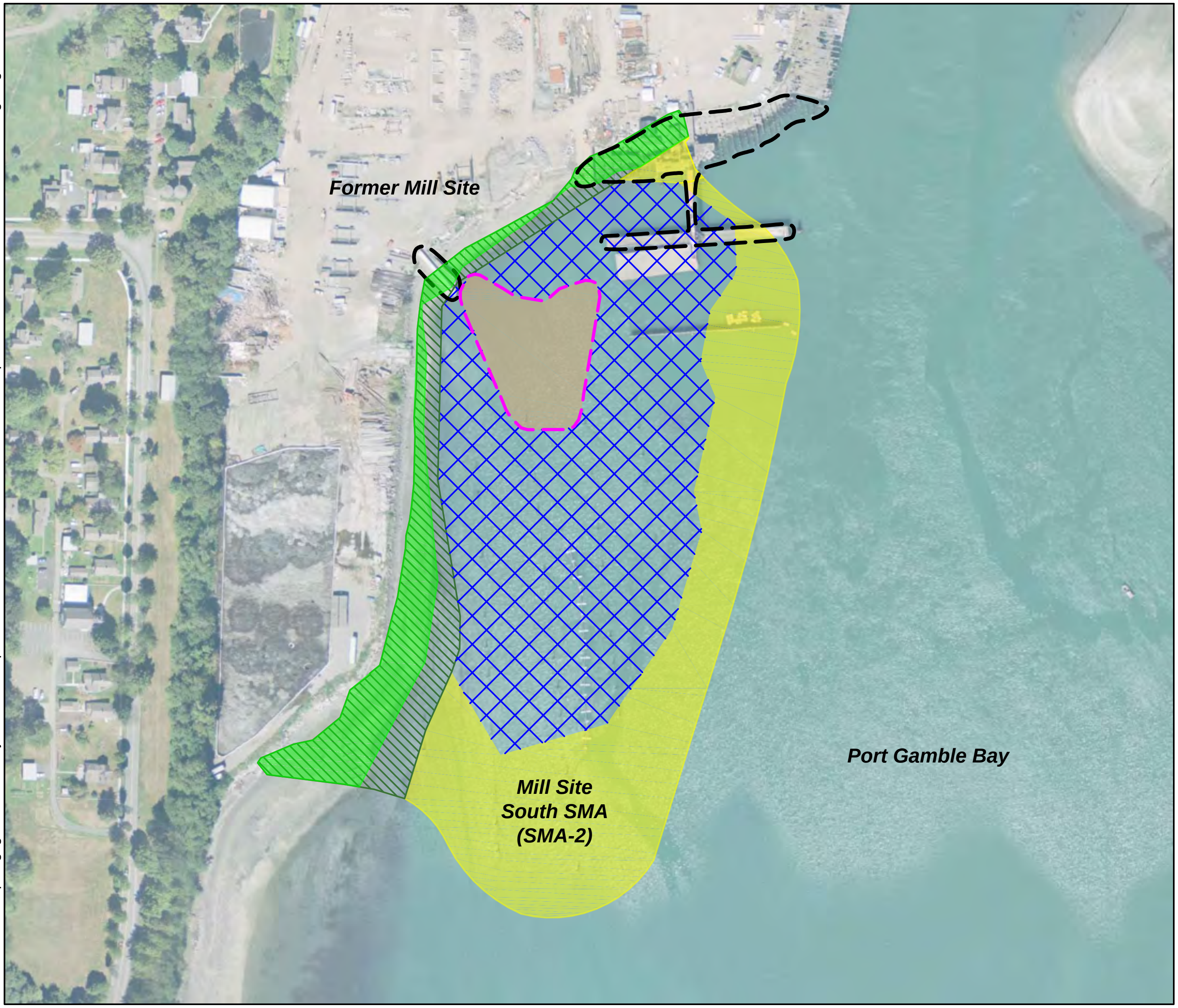
Figure 6-5
MSS Dredge Alternative
Port Gamble Bay Feasability Study



LEGEND:

- Dredge Wood Waste > 15% TVS with Residuals Cover
- Intertidal Cap
- Intertidal Cap Excavation
- 1-ft Thick Benthic Cap
- EMNR
- Demolition Area
- 2007 Dredge and Cap Area

0 300
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

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Figure 6-6
MSS Dredge 1 and Cap Alternative
Port Gamble Bay Feasability Study

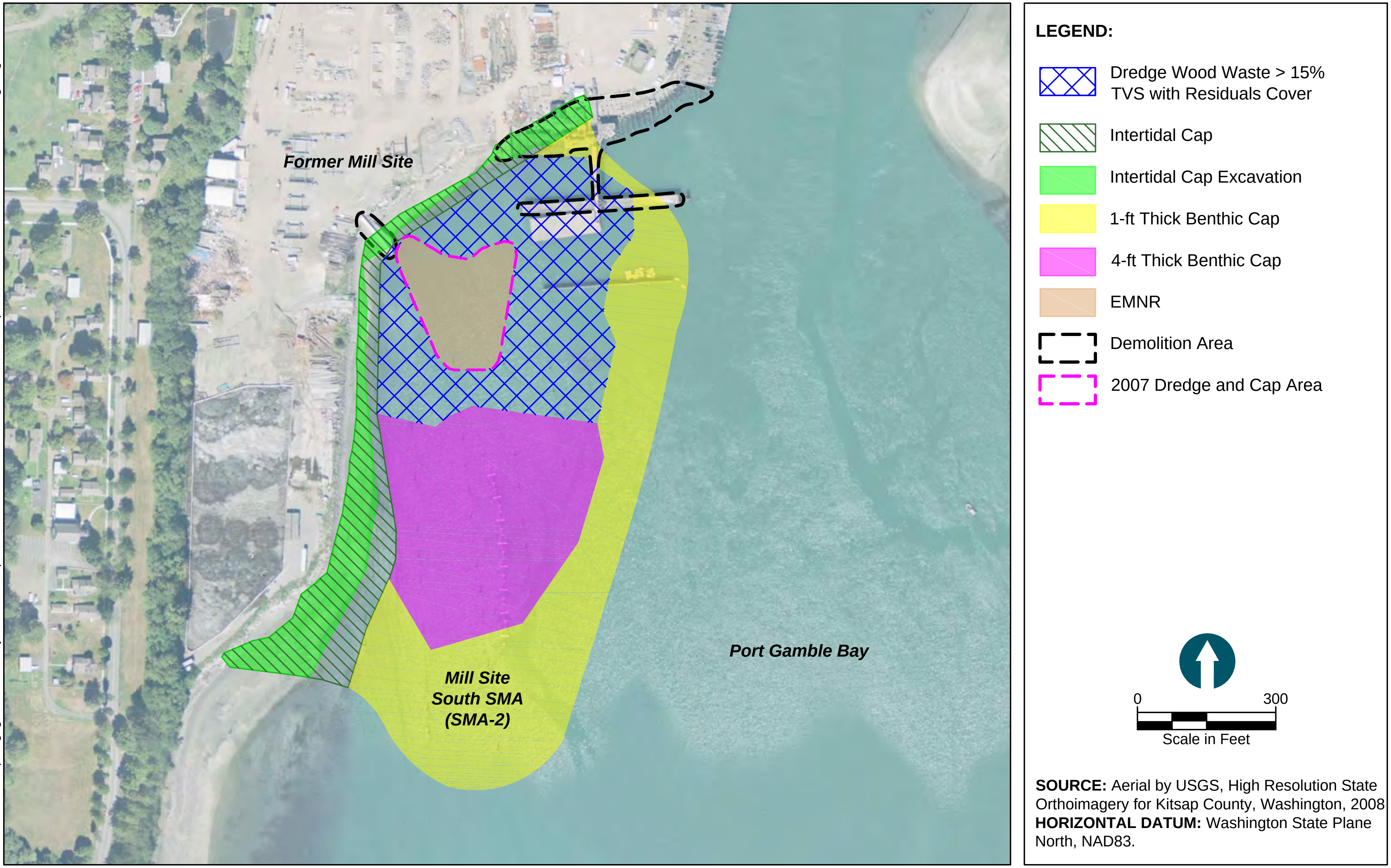

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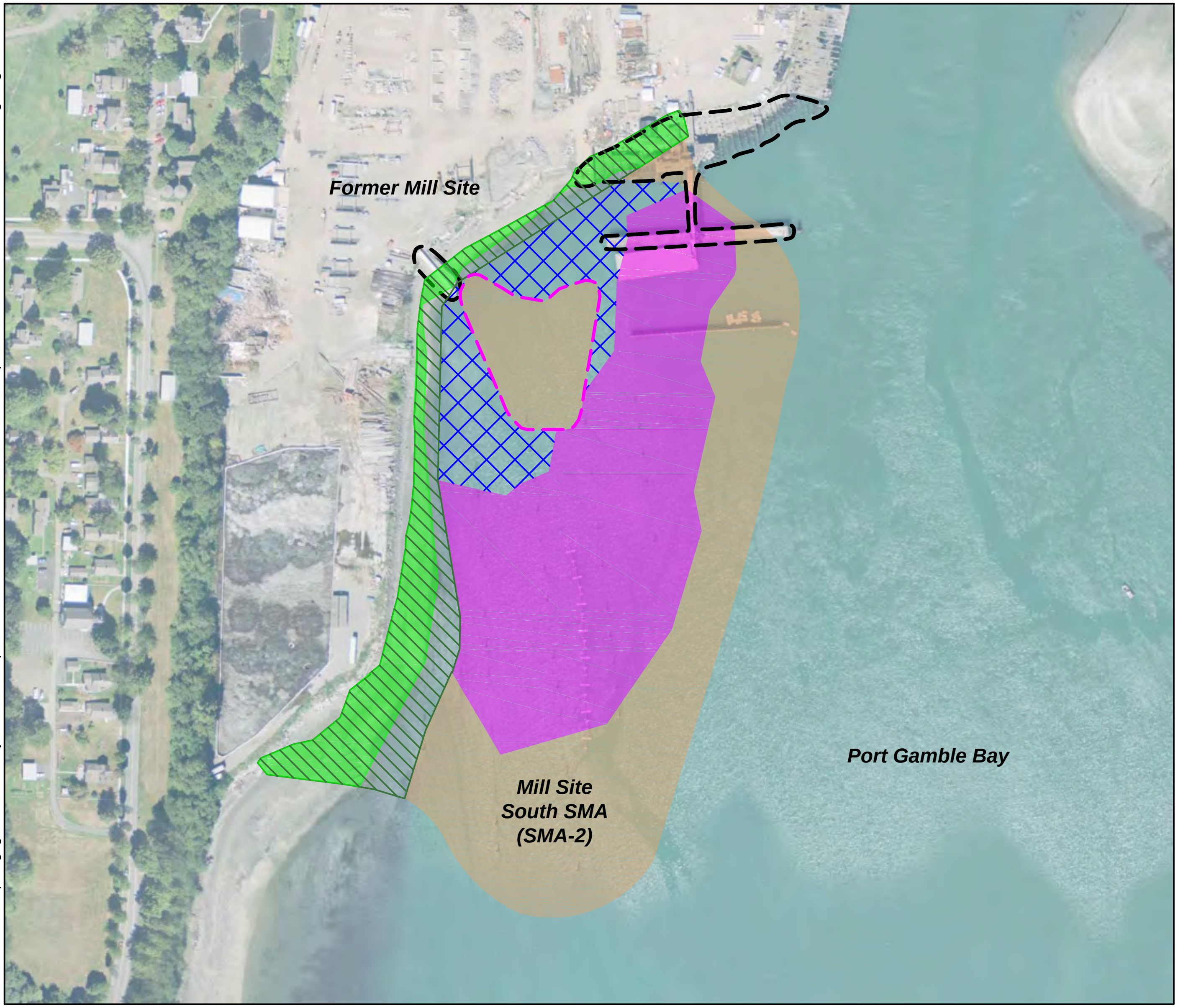
Figure 6-7
MSS Dredge 2 and Cap Alternative
Port Gamble Bay Feasability Study



LEGEND:

- Dredge Wood Waste > 15% TVS with Residuals Cover
- Intertidal Cap
- Intertidal Cap Excavation
- 4-ft Thick Benthic Cap
- EMNR
- Demolition Area
- 2007 Dredge and Cap Area

0 300
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

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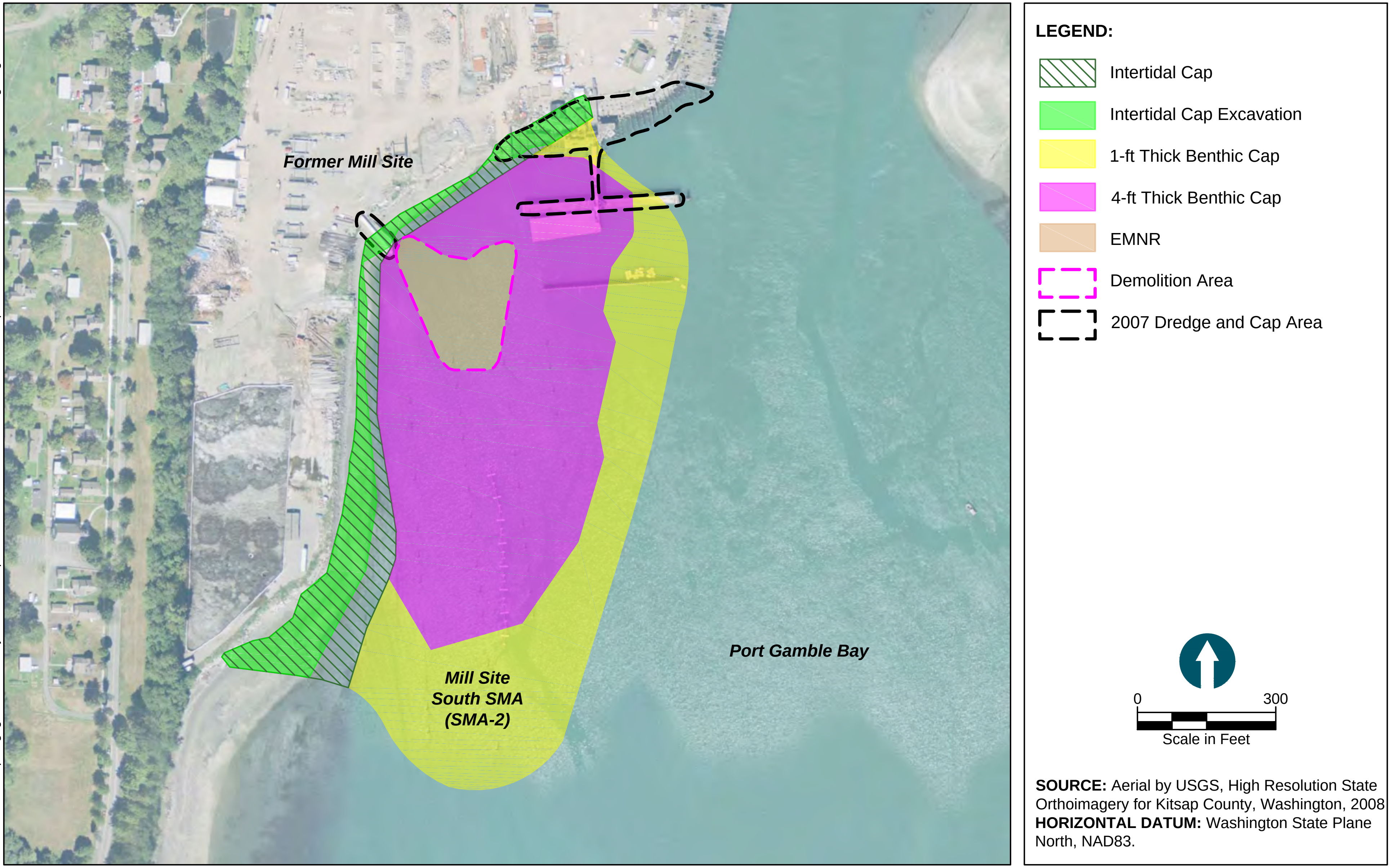
ANCHOR QEA

Figure 6-8
MSS Dredge, Cap, and EMNR Alterative
Port Gamble Bay Feasability Study



SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

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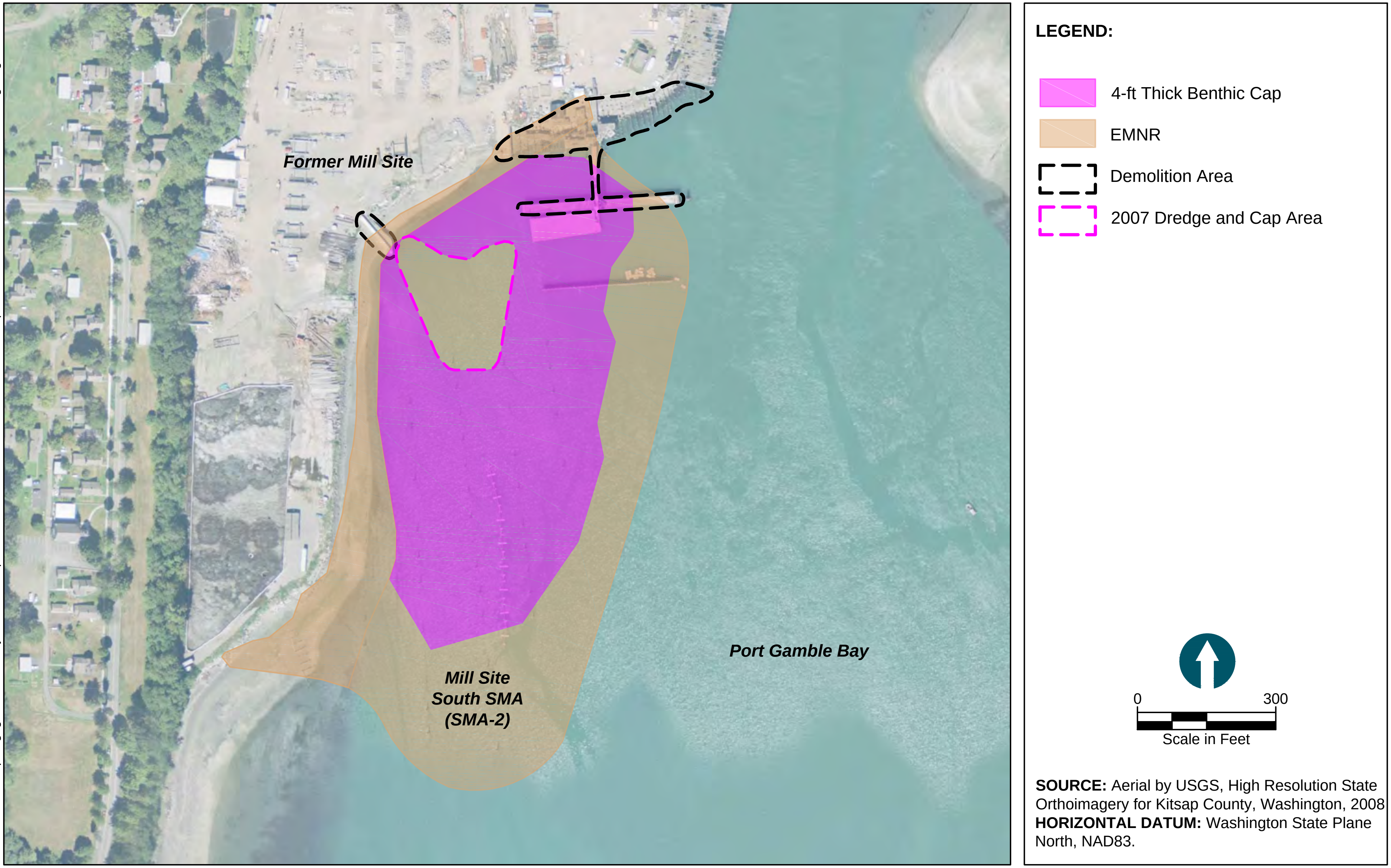
ANCHOR QEA

Figure 6-9
MSS Cap Alternative
Port Gamble Bay Feasability Study



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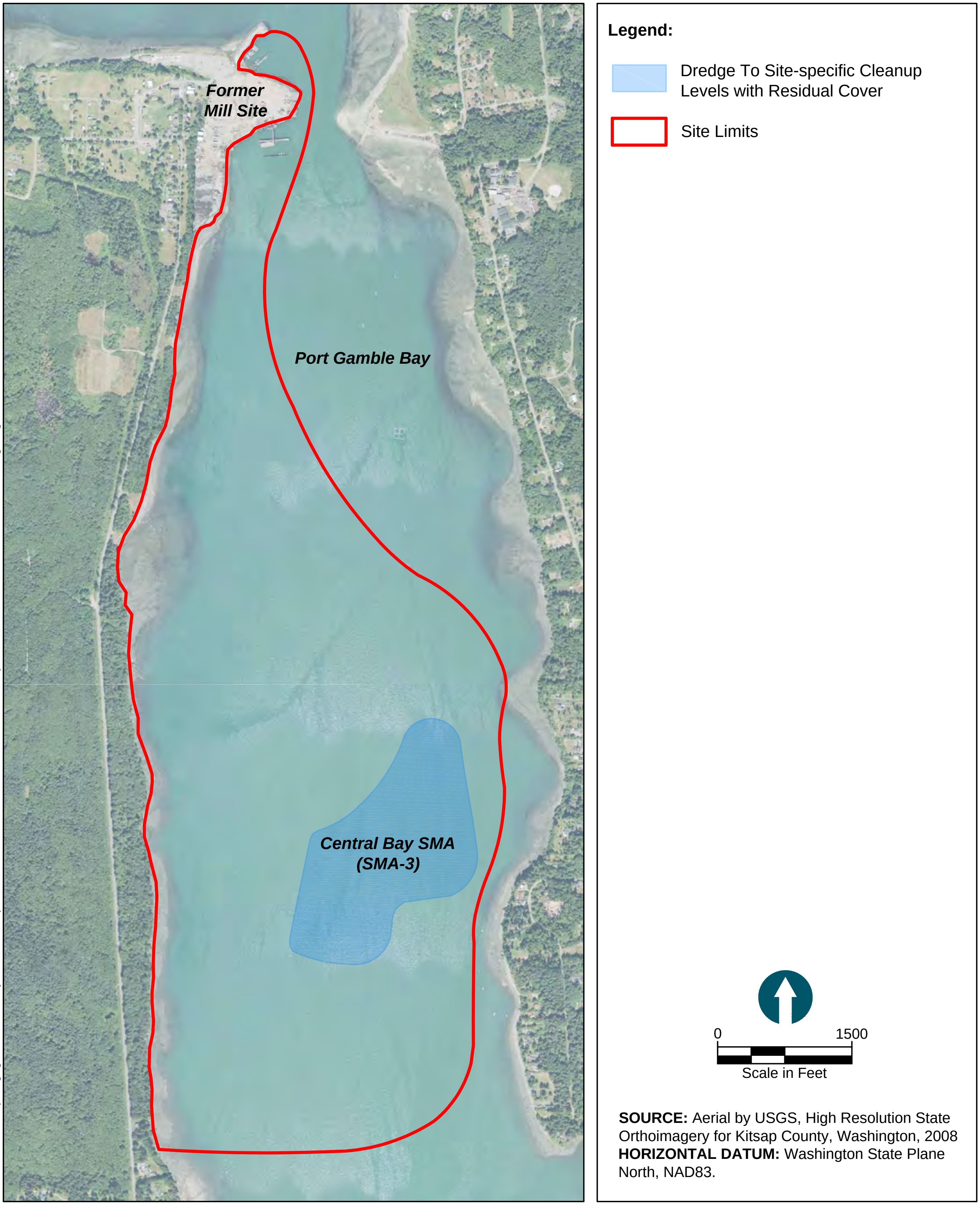
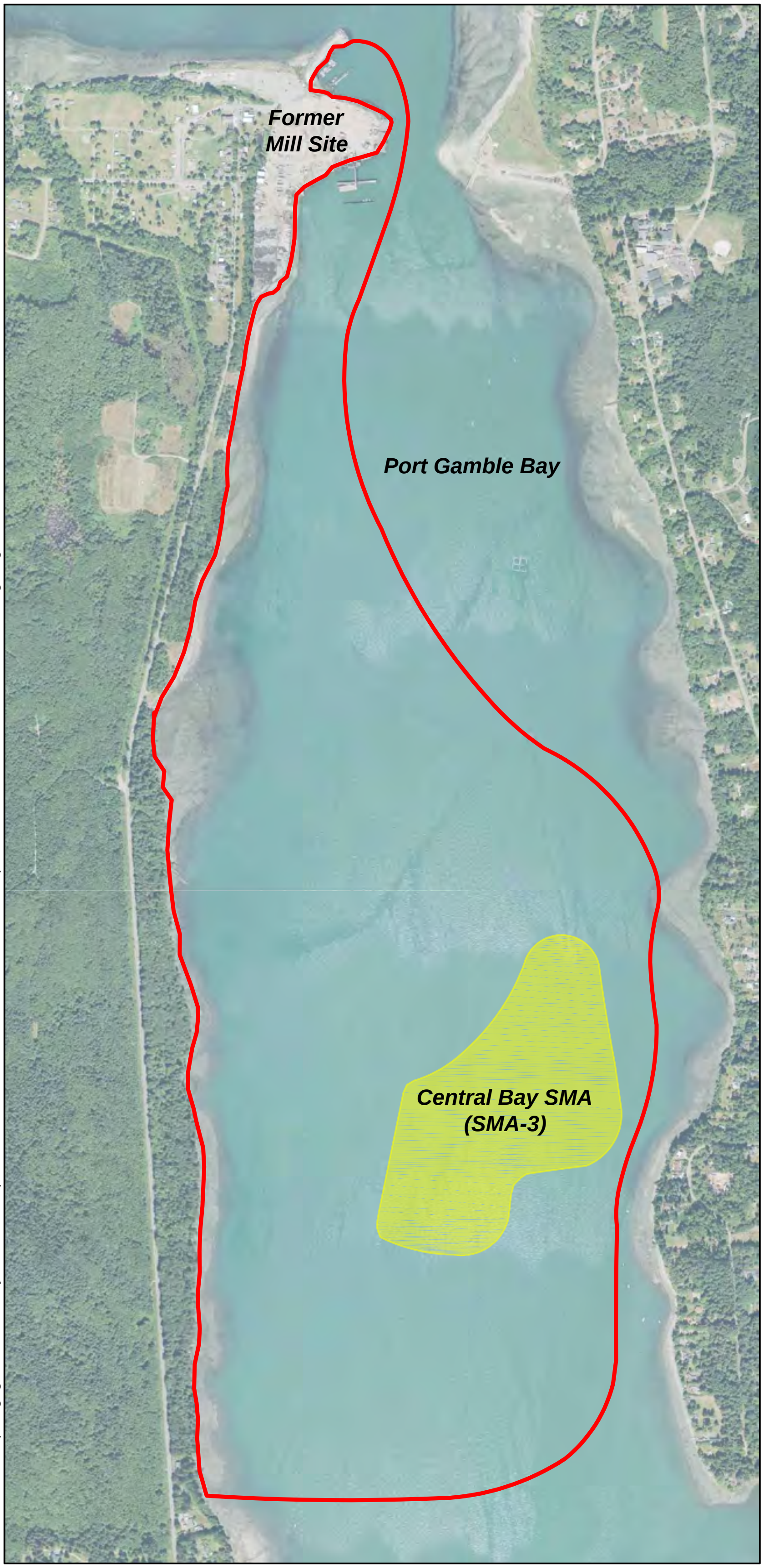
ANCHOR QEA

Figure 6-10
MSS Cap and EMNR Alternative
Port Gamble Bay Feasability Study



ANCHOR QEA

Figure 6-11
Central Bay Dredge Alternative
Port Gamble Bay Feasability Study



Legend:

1-ft Thick Benthic Cap

Site Limits

0 1500
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

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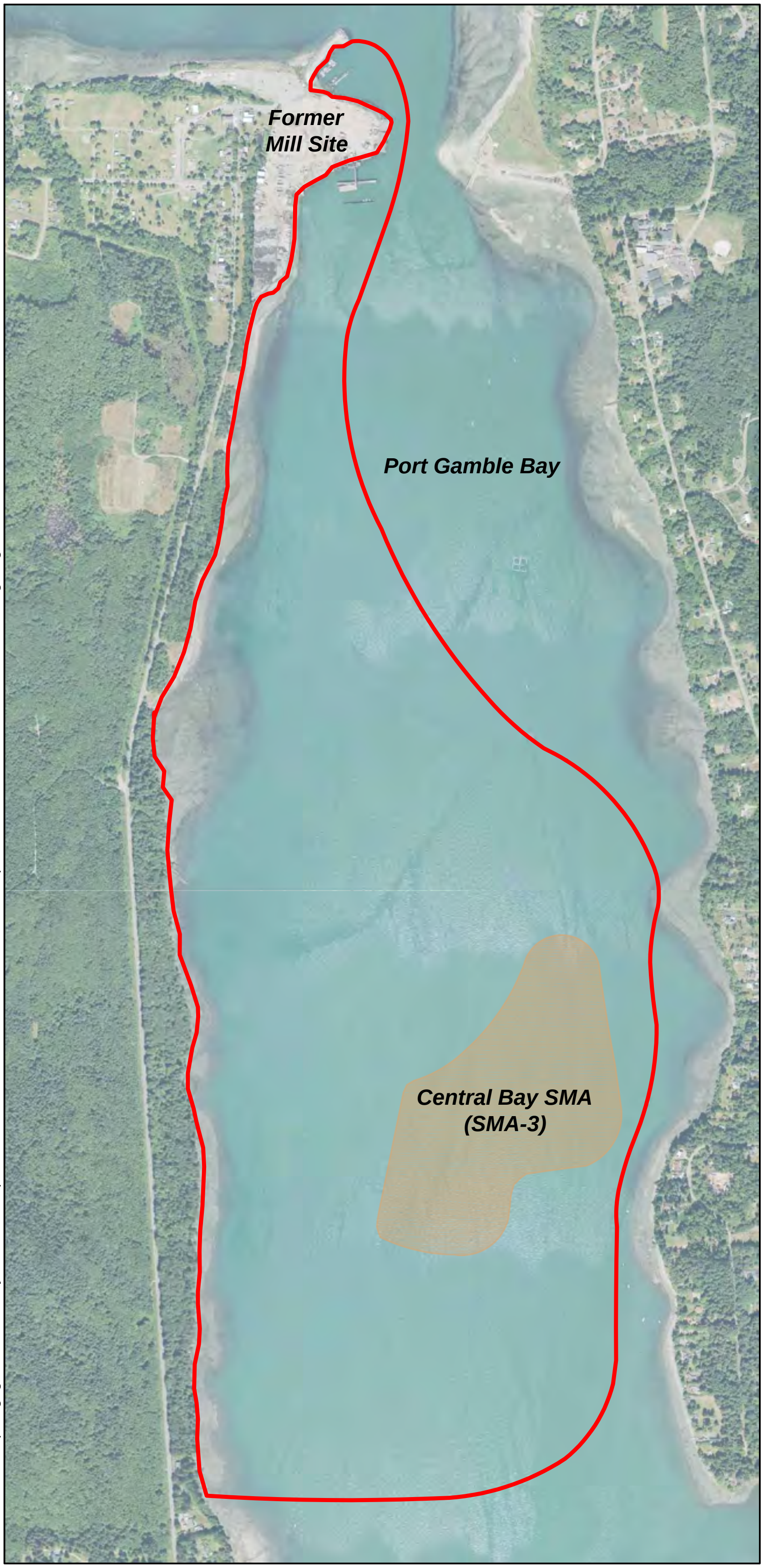
ANCHOR QEA

Figure 6-12
Central Bay Cap Alternative
Port Gamble Bay Feasability Study



Legend:

EMNR

Site Limits

0 1500

Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

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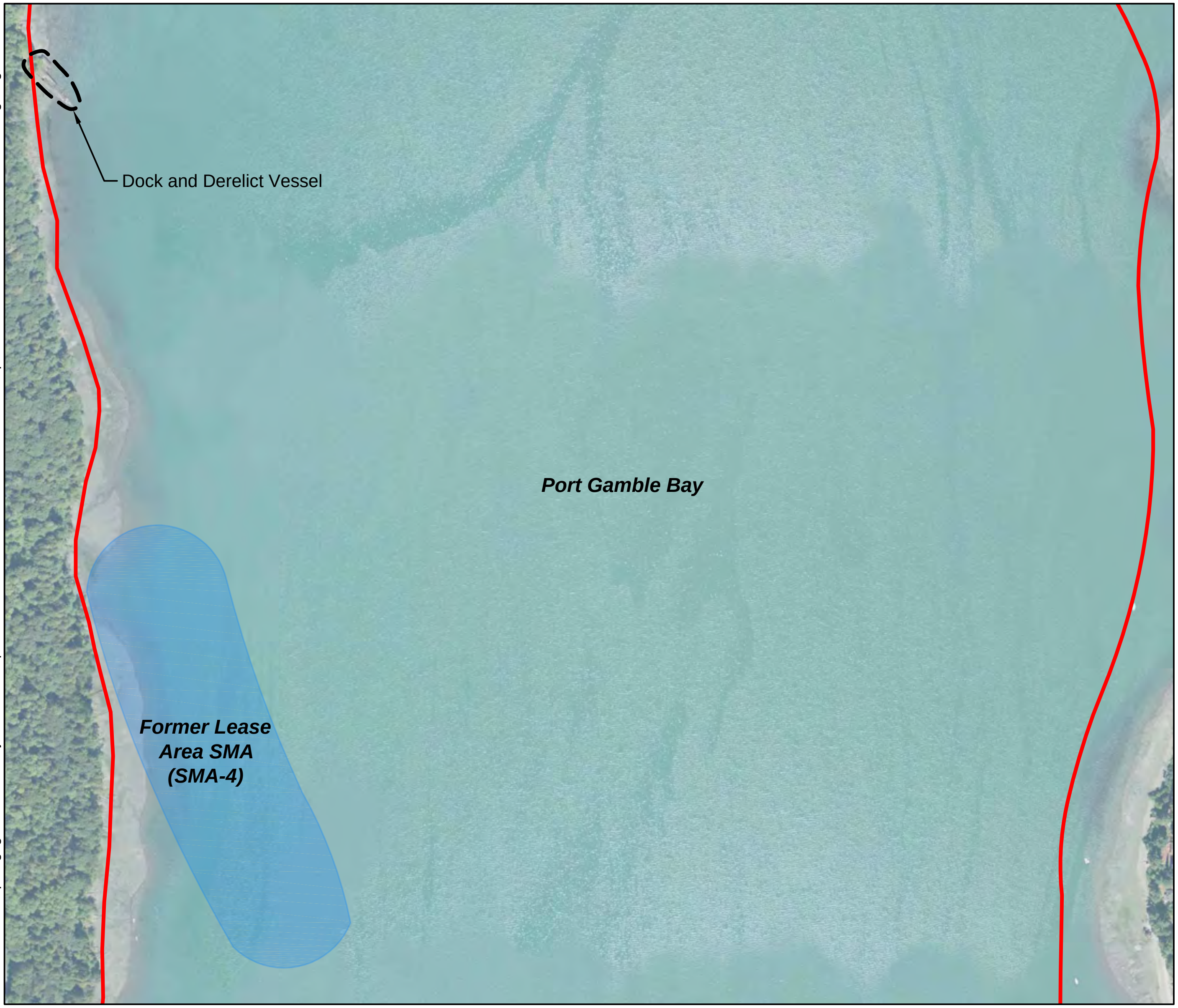
ANCHOR QEA

Figure 6-13
Central Bay EMNR Alternative
Port Gamble Bay Feasability Study



Legend:

- Dredge to Site-Specific Cleanup Levels with Residual Cover
- Demolition Area
- Site Limits

0 600
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

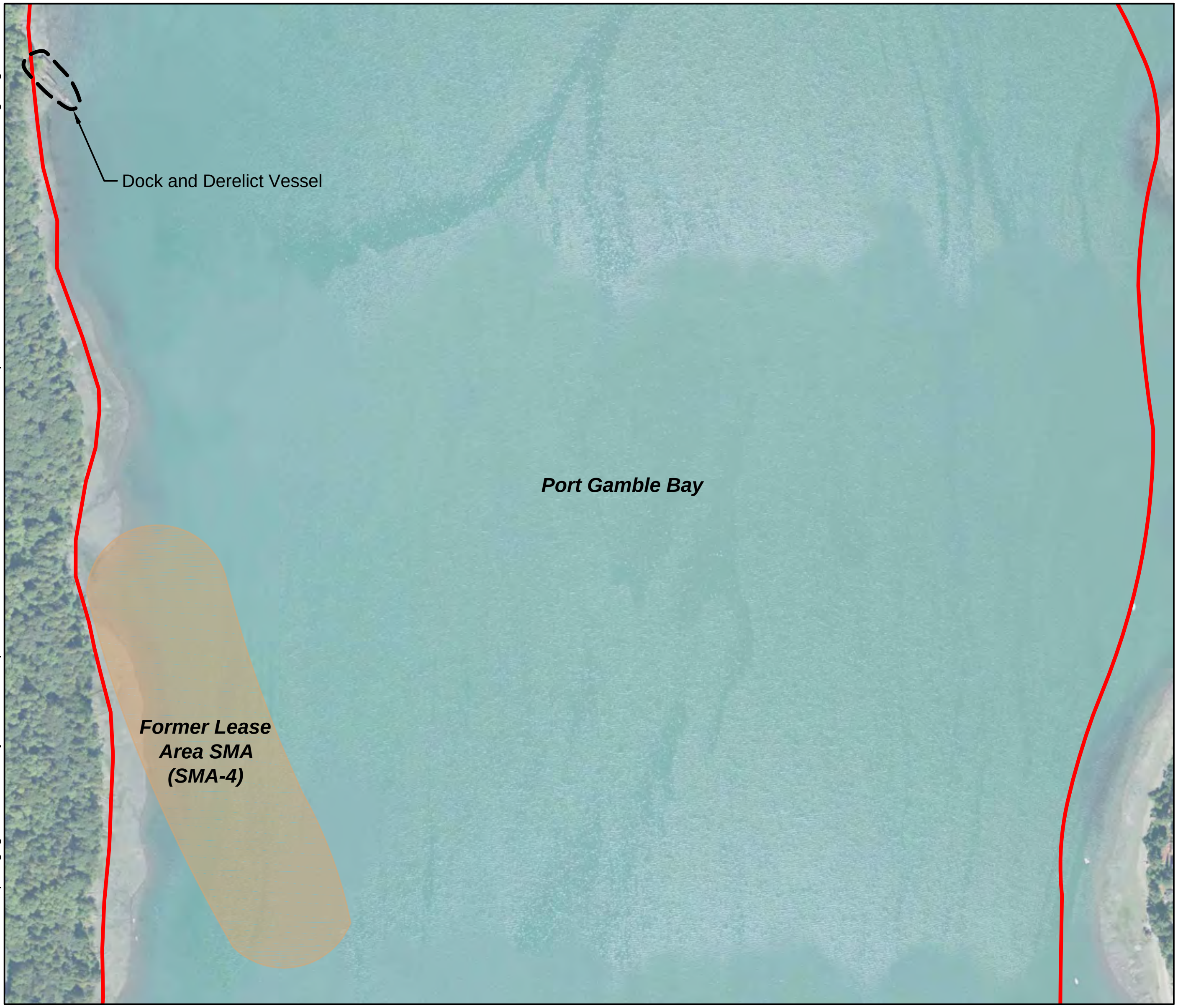
ANCHOR QEA

Figure 6-14
FLA Dredge Alternative
Port Gamble Bay Feasability Study

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

ANCHOR QEA

Figure 6-15
FLA Cap Alternative
Port Gamble Bay Feasability Study



Legend:

EMNR

Demolition Area

Site Limits

0 600

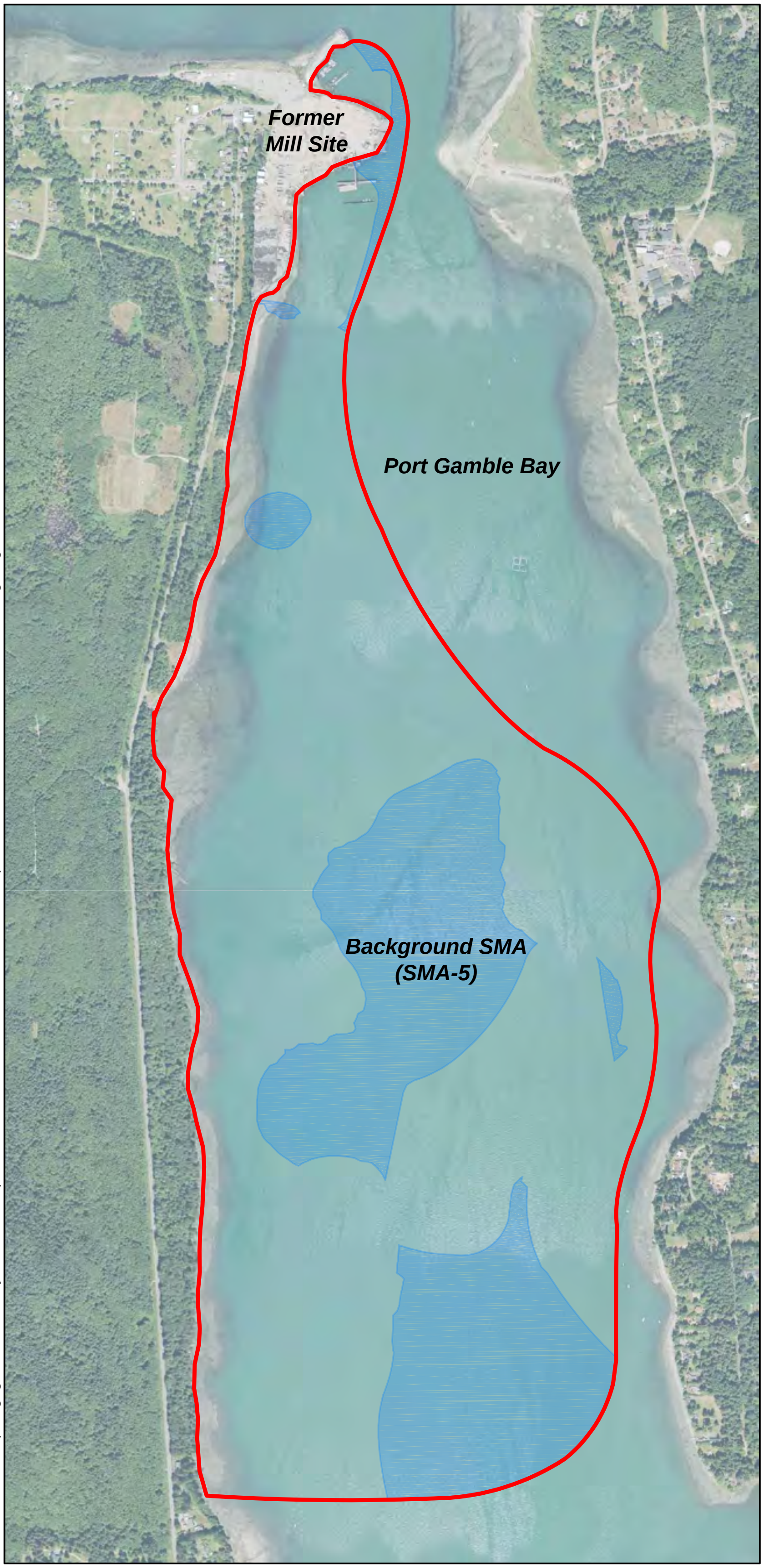
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

Jul 25, 2012 4:45pm tgriga K:\Projects\0388-Pope Resources\Port Gamble Sediment Cleanup RI-FS\FS\0388-RP-FS Alternatives.dwg Figure 6-16

ANCHOR QEA

Figure 6-16
FLA EMNR Alternative
Port Gamble Bay Feasability Study



Legend:

Dredge to Site-Specific Cleanup Levels with Residual Cover Areas that Exceed 3x Cleanup Level

Site Limits

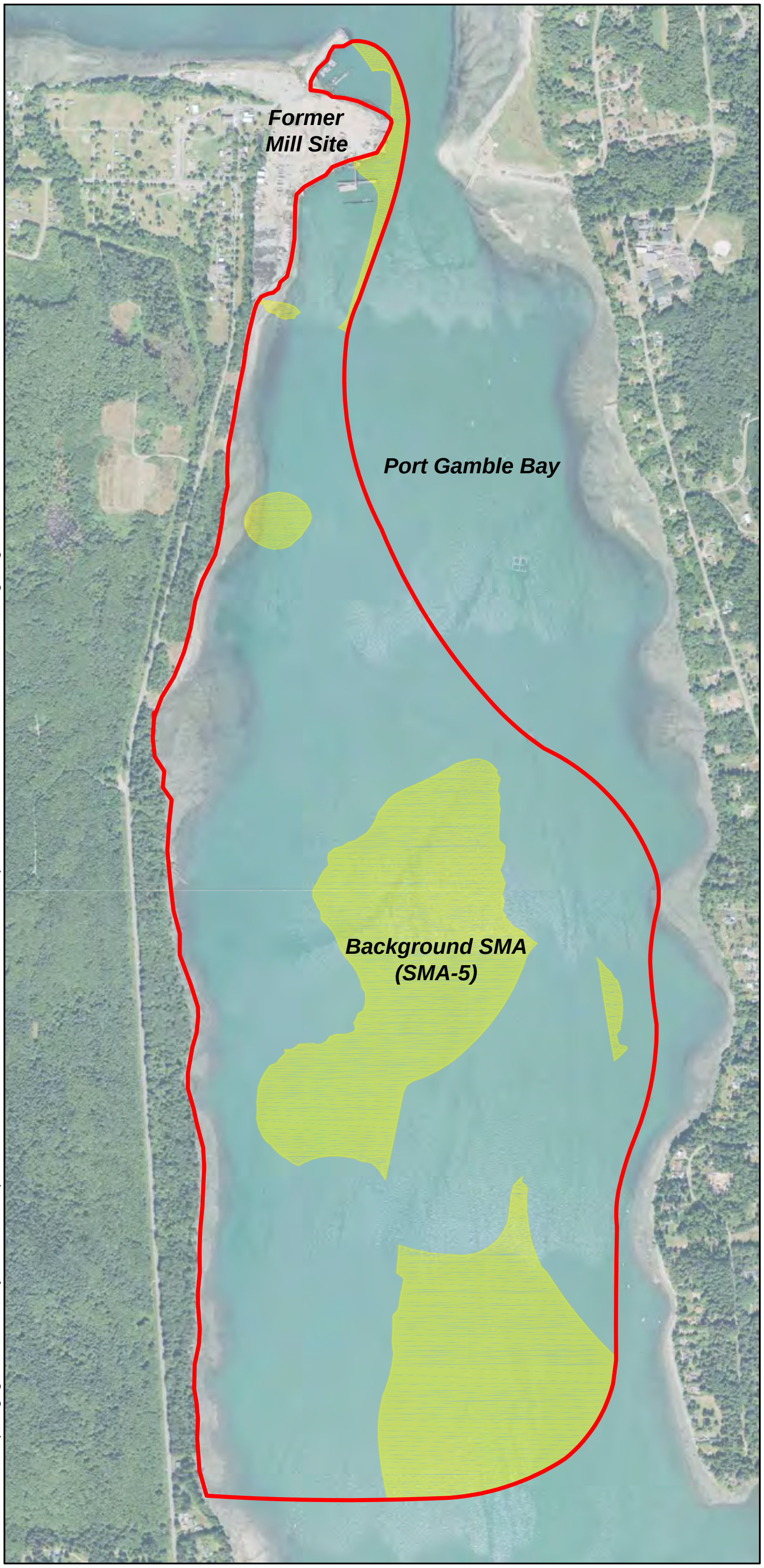
0 1500
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

Jul 25, 2012 4:45pm tgriga K:\Projects\0388-Pope Resources\Port Gamble Sediment Cleanup RI-FS\FS\0388-RP-FS Alternatives.dwg Figure 6-17

ANCHOR QEA

Figure 6-17
Background Area Dredge Alternative
Port Gamble Bay Feasability Study



Legend:

1-ft Thick Benthic Cap over Areas that Exceed 3x Cleanup Level

Site Limits

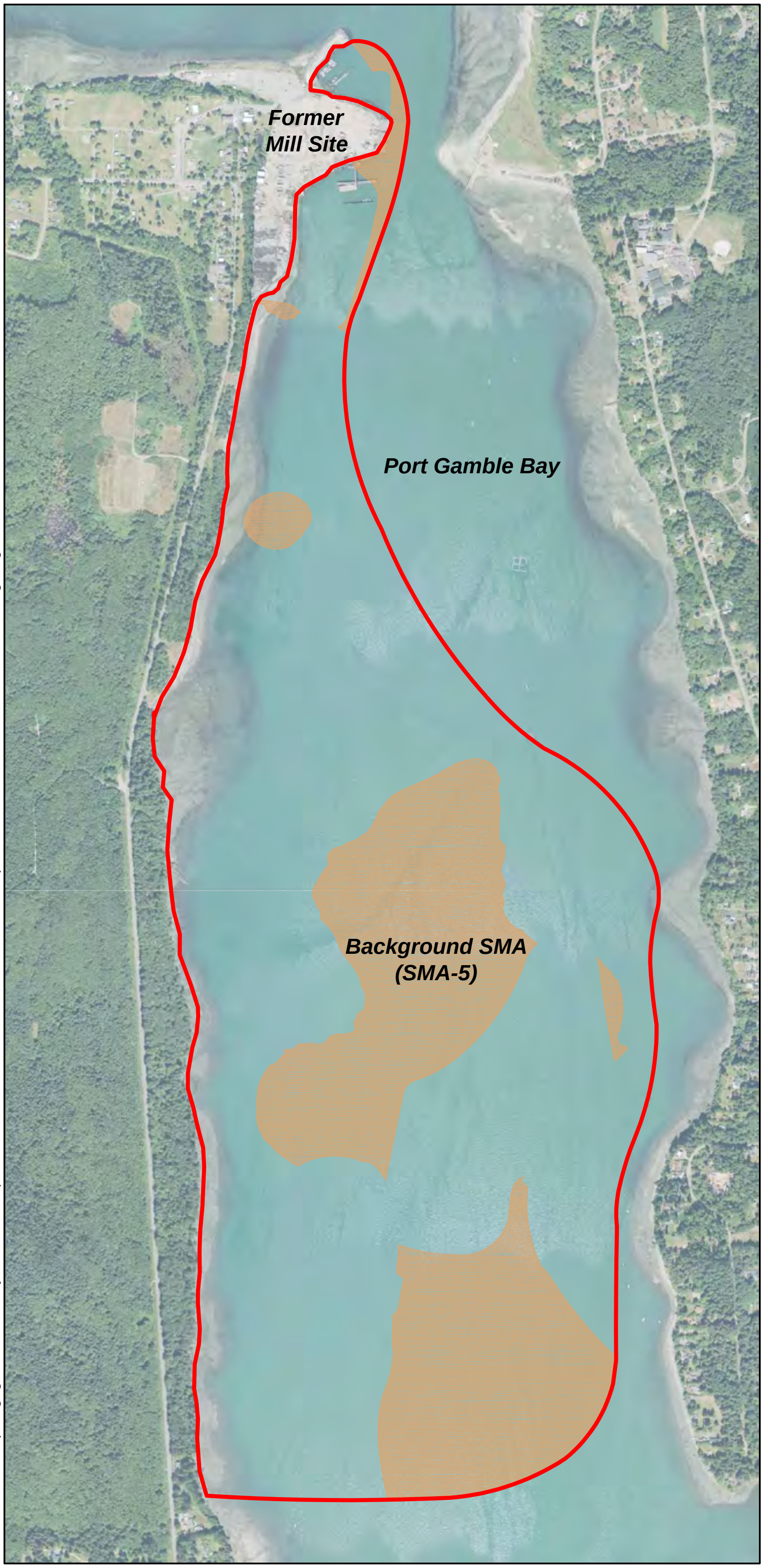
0 1500
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

Jul 25, 2012 4:45pm tgriga K:\Projects\0388-Pope Resources\Port Gamble Sediment Cleanup RI-FS\FS\0388-RP-FS Alternatives.dwg Figure 6-18

ANCHOR QEA

Figure 6-18
Background Area Cap Alternative
Port Gamble Bay Feasability Study



Legend:

EMNR in Areas that Exceed 3x Cleanup Level

Site Limits

0 1500
Scale in Feet

SOURCE: Aerial by USGS, High Resolution State Orthoimagery for Kitsap County, Washington, 2008
HORIZONTAL DATUM: Washington State Plane North, NAD83.

Jul 25, 2012 4:45pm tgriga K:\Projects\0388-Pope Resources\Port Gamble Sediment Cleanup RI-FS\FS\0388-RP-FS Alternatives.dwg Figure 6-19

ANCHOR QEA

Figure 6-19
Background Area EMNR Alternative
Port Gamble Bay Feasability Study

APPENDIX A
DETAILED COST ESTIMATES

Port Gamble Bay
Baywide Feasibility Study Cost Estimates

Summary of Detailed Costs 7/26/2012

	Low Estimate	Best Professional Judgement	High Estimate
Mill Site North - SMA 1 (6 acres)			
Alt 1 - Dredge	$ 5,000,000	$ 6,600,000	$ 10,200,000
Alt 2 - Dredge and Engineered Cap	$ 4,400,000	$ 4,900,000	$ 6,300,000
Alt 3 - Engineered Cap	$ 4,000,000	$ 4,000,000	$ 4,500,000
Alt 4 - Engineered Cap and EMNR	$ 3,900,000	$ 3,900,000	$ 4,400,000
Mill Site South - SMA 2 (19 acres)			
Alt 1 - Dredge	$ 16,400,000	$ 25,200,000	$ 37,900,000
Alt 2 - Dredge & Engineered Cap I	$ 12,500,000	$ 17,700,000	$ 25,900,000
Alt 3 - Dredge & Engineered Cap II	$ 9,800,000	$ 13,700,000	$ 20,400,000
Alt 4 - Dredge, Engineered Cap & EMNR	$ 6,700,000	$ 9,100,000	$ 13,500,000
Alt 5 - Engineered Cap	$ 5,100,000	$ 6,600,000	$ 10,000,000
Alt 6 - Engineered Cap and EMNR	$ 4,200,000	$ 5,700,000	$ 9,000,000
Central Bay - SMA 3 (77 acres)			
Alt 1 - Dredge	$ 36,400,000	$ 60,500,000	$ 92,900,000
Alt 2 - Engineered Cap	$ 4,900,000	$ 4,900,000	$ 8,700,000
Alt 3 - EMNR	$ 2,800,000	$ 2,800,000	$ 4,700,000
Alt 4 - Monitored Natural Recovery	$ 200,000	$ 300,000	$ 400,000
Former Lease Area - SMA 4 (19 acres)			
Alt 1 - Dredge	$ 9,600,000	$ 15,700,000	$ 23,700,000
Alt 2 - Engineered Cap	$ 1,800,000	$ 1,800,000	$ 2,700,000
Alt 3 - EMNR	$ 1,300,000	$ 1,300,000	$ 1,700,000
Alt 4 - Monitored Natural Recovery	$ 100,000	$ 150,000	$ 200,000
Background SMA-5 (cPAH Area - 196 acres)			
Alt 1 - Dredge	$ 90,800,000	$ 152,400,000	$ 235,100,000
Alt 2 - Engineered Cap	$ 11,600,000	$ 11,600,000	$ 21,200,000
Alt 3 - EMNR	$ 6,100,000	$ 6,100,000	$ 10,900,000
Alt 4 - Monitored Natural Recovery	$ 300,000	$ 400,000	$ 500,000

1. Costs include engineering, design, permitting, and construction management, which range from 25 to 35% of overall total.

2. Low end costs assume some use of open water disposal (100% of volume for Mill Site North; 50% elsewhere, excluding debris); reuse of sand for caps & EMNR cover from an existing dredging project (i.e. nominal cost to divert material otherwise destined for open water disposal) an 1.0x scaling factor on dredge volumes consistent with previous FS work.

3. BPJ costs assume open water disposal for dredge material consistent with low end estimate assumptions, mining of cap & EMNR cover sand from an open water or beneficial reuse site, and 1.25x scaling factor on preliminary dredge volumes, consistent with more recent sediment FS guidance.

4. High end costs assume upland disposal for dredge material, mining of cap & EMNR cover sand from an open water or beneficial reuse site, and 1.5x scaling factor on preliminary dredge volumes, consistent with more recent sediment FS guidance.

5. Combined project that addresses all SMAs would be expected to have a lower cost due to potential efficiencies in design, permitting, and construction management.

Port Gamble Bay
Baywide Feasibility Study Cost Estimates

Summary of Volumes and Durations 7/26/2012

DRAFT

	Dredge Vol (cy)	Cap Vol (ton)	Duration (days)	Duration (seasons)
Mill Site North - SMA 1 (6 acres)				
Alt 1 - Dredge	41,000	6,900	58	0.7
Alt 2 - Dredge and Engineered Cap	13,125	16,400	26	0.3
Alt 3 - Engineered Cap	-	26,100	13	0.2
Alt 4 - Engineered Cap and EMNR	-	22,500	11	0.1
Mill Site South - SMA 2 (19 acres)				
Alt 1 - Dredge	170,700	23,200	239	3.0
Alt 2 - Dredge & Engineered Cap I	99,900	40,600	154	1.9
Alt 3 - Dredge & Engineered Cap II	62,800	77,000	122	1.5
Alt 4 - Dredge, Engineered Cap & EMNR	23,600	91,800	77	1.0
Alt 5 - Engineered Cap	-	116,400	58	0.7
Alt 6 - Engineered Cap and EMNR	-	112,300	56	0.7
Central Bay - SMA 3 (77 acres)				
Alt 1 - Dredge	466,000	93,200	668	8.5
Alt 2 - Engineered Cap	-	186,300	93	1.2
Alt 3 - EMNR	-	93,200	47	0.6
Alt 4 - Monitored Natural Recovery	-	-	-	-
Former Lease Area - SMA 4 (19 acres)				
Alt 1 - Dredge	116,000	23,100	166	2.1
Alt 2 - Engineered Cap	-	46,200	23	0.3
Alt 3 - EMNR	-	23,100	12	0.2
Alt 4 - Monitored Natural Recovery	-	-	-	
Background SMA-5 (cPAH Area - 196 acres)				
Alt 1 - Dredge	1,190,000	237,900	1,706	21.6
Alt 2 - Engineered Cap	-	475,900	238	3.0
Alt 3 - EMNR	-	237,900	119	1.5
Alt 4 - Monitored Natural Recovery	-	-	-	-

1. Dredge production rate = 750 cy/day; Cap production rate = 2,000 tons/day; Fish window assumed to be Nov. 15 to Feb. 15; Work week = 6 days
2. Volumes based on "Best Professional Judgement" scenario from each detail spreadsheet

SMA-1 - Dredge

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 25,000	$ 25,000	1	LS	$ 25,000	$ 25,000	1	LS	$ 100,000	$ 100,000
Demolition												
Dock Demolition (including piles)	38,900	SF	$ 25	$ 972,500	38,900	SF	$ 25	$ 972,500	38,900	SF	$ 25	$ 972,500
Pile Pulling	700	EA	$ 400	$ 280,000	700	EA	$ 400	$ 280,000	700	EA	$ 400	$ 280,000
Transportation and Disposal	1,673	TON	$ 100	$ 167,250	1,673	TON	$ 100	$ 167,250	1,673	TON	$ 100	$ 167,250
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	33,000	CY	$ 20	$ 660,000	41,000	CY	$ 20	$ 820,000	50,000	CY	$ 20	$ 1,000,000
Transportation and Disposal (Open Water)	29,700	CY	$ 5	$ 148,500	29,520	CY	$ 5	$ 147,600	20,000	CY	$ 5	$ 100,000
Offload, Transportation and Disposal (Upland)	-	TON	$ 60	$ -	11,070	TON	$ 60	$ 664,200	30,000	TON	$ 60	$ 1,800,000
Debris Screening/Offload/Transport & Dispose	4,950	TON	$ 75	$ 371,250	6,150	TON	$ 75	$ 461,250	15,000	TON	$ 75	$ 1,125,000
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	6,900	TON	$ 8	$ 55,200	6,900	TON	$ 8	$ 55,200	6,900	TON	$ 15	$ 103,500
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place EMNR/Residuals Cover Sand	6,900	TON	$ 5	$ 34,500	6,900	TON	$ 5	$ 34,500	6,900	TON	$ 10	$ 69,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 2,840,000				$ 3,760,000				$ 5,850,000
Construction Contingency	30	%		$ 852,000	30	%		$ 1,128,000	30	%		$ 1,755,000
Total Construction Cost				**$ 3,690,000**				**$ 4,890,000**				**$ 7,610,000**
Project Management	5	%		$ 184,500	5	%		$ 244,500	5	%		$ 380,500
Engineering and Design	10	%		$ 369,000	10	%		$ 489,000	10	%		$ 761,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 369,000	10	%		$ 489,000	10	%		$ 761,000
Environmental Monitoring during Construction	8	WEEK	$ 12,500	$ 100,000	10	WEEK	$ 12,500	$ 125,000	12	WEEK	$ 12,500	$ 150,000
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 184,500	5	%		$ 244,500	5	%		$ 380,500
Total Non-Construction Cost				**$ 1,340,000**				**$ 1,730,000**				**$ 2,570,000**
Total Cost				**$ 5,030,000**				**$ 6,620,000**				**$ 10,180,000**

Port Gamble Mill Site Marine Area Feasibility Study 7/26/2012

SMA-1 - Dredge and Engineered Cap

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 25,000	$ 25,000	1	LS	$ 25,000	$ 25,000	1	LS	$ 100,000	$ 100,000
Demolition												
Dock Demolition (including piles)	38,900	SF	$ 25	$ 972,500	38,900	SF	$ 25	$ 972,500	38,900	SF	$ 25	$ 972,500
Pile Pulling	700	EA	$ 400	$ 280,000	700	EA	$ 400	$ 280,000	700	EA	$ 400	$ 280,000
Transportation and Disposal	1,673	TON	$ 100	$ 167,250	1,673	TON	$ 100	$ 167,250	1,673	TON	$ 100	$ 167,250
Dredging and Disposal												
Upland Excavation	2,900	CY	$ 10	$ 29,000	2,900	CY	$ 10	$ 29,000	2,900	CY	$ 10	$ 29,000
Upland Transportation and Disposal	4,350	TON	$ 50	$ 217,500	4,350	TON	$ 50	$ 217,500	4,350	TON	$ 50	$ 217,500
Dredging	10,500	CY	$ 20	$ 210,000	13,125	CY	$ 20	$ 262,500	15,750	CY	$ 20	$ 315,000
Transportation and Disposal (Open Water)	9,450	CY	$ 5	$ 47,250	9,450	CY	$ 5	$ 47,250	6,300	CY	$ 5	$ 31,500
Offload, Transportation and Disposal (Upland)	-	TON	$ 60	$ -	3,544	TON	$ 60	$ 212,625	9,450	TON	$ 60	$ 567,000
Debris Screening/Offload/Transport & Dispose	1,575	TON	$ 75	$ 118,125	1,969	TON	$ 75	$ 147,656	4,725	TON	$ 75	$ 354,375
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	7,900	TON	$ 15	$ 118,500	7,900	TON	$ 15	$ 118,500	7,900	TON	$ 15	$ 118,500
Purchase & Transport Type II Sand	7,300	TON	$ 8	$ 58,400	7,300	TON	$ 8	$ 58,400	7,300	TON	$ 15	$ 109,500
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	1,200	TON	$ 8	$ 9,600	1,200	TON	$ 8	$ 9,600	1,200	TON	$ 15	$ 18,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	7,900	TON	$ 10	$ 79,000	7,900	TON	$ 10	$ 79,000	7,900	TON	$ 13	$ 105,307
Place Type II and Type III Cap Sand	7,300	TON	$ 5	$ 36,500	7,300	TON	$ 5	$ 36,500	7,300	TON	$ 10	$ 73,000
Place EMNR/Residuals Cover Sand	1,200	TON	$ 5	$ 6,000	1,200	TON	$ 5	$ 6,000	1,200	TON	$ 10	$ 12,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 2,500,000				$ 2,800,000				$ 3,600,000
Construction Contingency	30	%		$ 750,000	30	%		$ 840,000	30	%		$ 1,080,000
Total Construction Cost				**$ 3,250,000**				**$ 3,640,000**				**$ 4,680,000**
Project Management	5	%		$ 162,500	5	%		$ 182,000	5	%		$ 234,000
Engineering and Design	10	%		$ 325,000	10	%		$ 364,000	10	%		$ 468,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 325,000	10	%		$ 364,000	10	%		$ 468,000
Environmental Monitoring during Construction	4	WEEK	$ 12,500	$ 50,000	4	WEEK	$ 12,500	$ 50,000	5	WEEK	$ 12,500	$ 62,500
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 162,500	5	%		$ 182,000	5	%		$ 234,000
Total Non-Construction Cost				**$ 1,160,000**				**$ 1,280,000**				**$ 1,600,000**
Total Cost				**$ 4,410,000**				**$ 4,920,000**				**$ 6,280,000**

SMA-1 - Engineered Cap

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 25,000	$ 25,000	1	LS	$ 25,000	$ 25,000	1	LS	$ 100,000	$ 100,000
Demolition												
Dock Demolition (including piles)	38,900	SF	$ 25	$ 972,500	38,900	SF	$ 25	$ 972,500	38,900	SF	$ 25	$ 972,500
Pile Pulling	700	EA	$ 400	$ 280,000	700	EA	$ 400	$ 280,000	700	EA	$ 400	$ 280,000
Transportation and Disposal	1,673	TON	$ 100	$ 167,250	1,673	TON	$ 100	$ 167,250	1,673	TON	$ 100	$ 167,250
Dredging and Disposal												
Upland Excavation	2,900	CY	$ 10	$ 29,000	2,900	CY	$ 10	$ 29,000	2,900	CY	$ 10	$ 29,000
Upland Transportation and Disposal	4,350	TON	$ 50	$ 217,500	4,350	TON	$ 50	$ 217,500	4,350	TON	$ 50	$ 217,500
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Offload, Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	7,900	TON	$ 15	$ 118,500	7,900	TON	$ 15	$ 118,500	7,900	TON	$ 15	$ 118,500
Purchase & Transport Type II Sand	7,300	TON	$ 8	$ 58,400	7,300	TON	$ 8	$ 58,400	7,300	TON	$ 15	$ 109,500
Purchase & Transport Type III Sand	9,700	TON	$ 8	$ 77,600	9,700	TON	$ 8	$ 77,600	9,700	TON	$ 15	$ 145,500
Purchase & Transport EMNR/Residuals Cover Sand	1,200	TON	$ 8	$ 9,600	1,200	TON	$ 8	$ 9,600	1,200	TON	$ 15	$ 18,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	7,900	TON	$ 10	$ 79,000	7,900	TON	$ 10	$ 79,000	7,900	TON	$ 13	$ 105,307
Place Type II and Type III Cap Sand	17,000	TON	$ 5	$ 85,000	17,000	TON	$ 5	$ 85,000	17,000	TON	$ 10	$ 170,000
Place EMNR/Residuals Cover Sand	1,200	TON	$ 5	$ 6,000	1,200	TON	$ 5	$ 6,000	1,200	TON	$ 10	$ 12,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 2,260,000				$ 2,260,000				$ 2,580,000
Construction Contingency	30	%		$ 678,000	30	%		$ 678,000	30	%		$ 774,000
Total Construction Cost				**$ 2,940,000**				**$ 2,940,000**				**$ 3,350,000**
Project Management	5	%		$ 147,000	5	%		$ 147,000	5	%		$ 167,500
Engineering and Design	10	%		$ 294,000	10	%		$ 294,000	10	%		$ 335,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 294,000	10	%		$ 294,000	10	%		$ 335,000
Environmental Monitoring during Construction	2	WEEK	$ 12,500	$ 25,000	2	WEEK	$ 12,500	$ 25,000	2	WEEK	$ 12,500	$ 25,000
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 147,000	5	%		$ 147,000	5	%		$ 167,500
Total Non-Construction Cost				**$ 1,040,000**				**$ 1,040,000**				**$ 1,170,000**
Total Cost				**$ 3,980,000**				**$ 3,980,000**				**$ 4,520,000**

SMA-1 - Engineered Cap & EMNR

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 25,000	$ 25,000	1	LS	$ 25,000	$ 25,000	1	LS	$ 100,000	$ 100,000
Demolition												
Dock Demolition (including piles)	38,900	SF	$ 25	$ 972,500	38,900	SF	$ 25	$ 972,500	38,900	SF	$ 25	$ 972,500
Pile Pulling	700	EA	$ 400	$ 280,000	700	EA	$ 400	$ 280,000	700	EA	$ 400	$ 280,000
Transportation and Disposal	1,673	TON	$ 100	$ 167,250	1,673	TON	$ 100	$ 167,250	1,673	TON	$ 100	$ 167,250
Dredging and Disposal												
Upland Excavation	2,900	CY	$ 10	$ 29,000	2,900	CY	$ 10	$ 29,000	2,900	CY	$ 10	$ 29,000
Upland Transportation and Disposal	4,350	TON	$ 50	$ 217,500	4,350	TON	$ 50	$ 217,500	4,350	TON	$ 50	$ 217,500
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Offload, Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	7,900	TON	$ 15	$ 118,500	7,900	TON	$ 15	$ 118,500	7,900	TON	$ 15	$ 118,500
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	9,700	TON	$ 8	$ 77,600	9,700	TON	$ 8	$ 77,600	9,700	TON	$ 15	$ 145,500
Purchase & Transport EMNR/Residuals Cover Sand	4,900	TON	$ 8	$ 39,200	4,900	TON	$ 8	$ 39,200	4,900	TON	$ 15	$ 73,500
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	7,900	TON	$ 10	$ 79,000	7,900	TON	$ 10	$ 79,000	7,900	TON	$ 13	$ 105,307
Place Type II and Type III Cap Sand	9,700	TON	$ 5	$ 48,500	9,700	TON	$ 5	$ 48,500	9,700	TON	$ 10	$ 97,000
Place EMNR/Residuals Cover Sand	4,900	TON	$ 5	$ 24,500	4,900	TON	$ 5	$ 24,500	4,900	TON	$ 10	$ 49,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 2,210,000				$ 2,210,000				$ 2,490,000
Construction Contingency	30	%		$ 663,000	30	%		$ 663,000	30	%		$ 747,000
Total Construction Cost				**$ 2,870,000**				**$ 2,870,000**				**$ 3,240,000**
Project Management	5	%		$ 143,500	5	%		$ 143,500	5	%		$ 162,000
Engineering and Design	10	%		$ 287,000	10	%		$ 287,000	10	%		$ 324,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 287,000	10	%		$ 287,000	10	%		$ 324,000
Environmental Monitoring during Construction	2	WEEK	$ 12,500	$ 25,000	2	WEEK	$ 12,500	$ 25,000	2	WEEK	$ 12,500	$ 25,000
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 143,500	5	%		$ 143,500	5	%		$ 162,000
Total Non-Construction Cost				**$ 1,020,000**				**$ 1,020,000**				**$ 1,130,000**
Total Cost				**$ 3,890,000**				**$ 3,890,000**				**$ 4,370,000**

Port Gamble Mill Site Marine Area Feasibility Study 7/26/2012

SMA-2 - Dredge

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000
Demolition												
Dock Demolition (including piles)	36,300	SF	$ 25	$ 907,500	36,300	SF	$ 25	$ 907,500	36,300	25	$ 45	$ 1,633,500
Pile Pulling	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000
Transportation and Disposal	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750
Excavation/Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	136,500	CY	$ 20	$ 2,730,000	170,700	CY	$ 20	$ 3,414,000	204,800	CY	$ 20	$ 4,096,000
Transportation and Disposal (Open Water)	92,138	CY	$ 5	$ 460,688	76,815	CY	$ 5	$ 384,075	46,080	CY	$ 5	$ 230,400
Offload, Transportation and Disposal (Upland)	46,069	TON	$ 60	$ 2,764,125	115,223	TON	$ 60	$ 6,913,350	207,360	TON	$ 60	$ 12,441,600
Debris Screening/Offload/Transport & Dispose	20,475	TON	$ 75	$ 1,535,625	25,605	TON	$ 75	$ 1,920,375	30,720	TON	$ 75	$ 2,304,000
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	23,200	TON	$ 8	$ 185,600	23,200	TON	$ 8	$ 185,600	23,200	TON	$ 15	$ 348,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place EMNR/Residuals Cover Sand	23,200	TON	$ 5	$ 116,000	23,200	TON	$ 5	$ 116,000	23,200	TON	$ 10	$ 232,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install	-	LF	$ 300	$ -	-	LF	$ 300	$ -	-	LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 9,410,288				$ 14,551,650				$ 21,996,250
Construction Contingency	30	%		$ 2,823,086	30	%		$ 4,365,495	30	%		$ 6,598,875
Total Construction Cost				**$ 12,230,000**				**$ 18,920,000**				**$ 28,600,000**
Project Management	5	%		$ 611,500	5	%		$ 946,000	5	%		$ 1,430,000
Engineering and Design	10	%		$ 1,223,000	10	%		$ 1,892,000	10	%		$ 2,860,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 1,223,000	10	%		$ 1,892,000	10	%		$ 2,860,000
Environmental Monitoring during Construction	32	WEEK	$ 12,500	$ 400,000	40	WEEK	$ 12,500	$ 500,000	47	WEEK	$ 12,500	$ 587,500
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 611,500	5	%		$ 946,000	5	%		$ 1,430,000
Total Non-Construction Cost				**$ 4,154,000**				**$ 6,261,000**				**$ 9,252,500**
Total Cost				**$ 16,380,000**				**$ 25,180,000**				**$ 37,850,000**

Port Gamble Mill Site Marine Area Feasibility Study 7/26/2012

SMA-2 - Dredge and Engineered Cap 1

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000
Demolition												
Dock Demolition (including piles)	36,300	SF	$ 25	$ 907,500	36,300	SF	$ 25	$ 907,500	36,300	25	$ 45	$ 1,633,500
Pile Pulling	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000
Transportation and Disposal	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750
Excavation/Dredging and Disposal												
Upland Excavation	5,500	CY	$ 10	$ 55,000	5,500	CY	$ 10	$ 55,000	5,500	CY	$ 10	$ 55,000
Upland Transportation and Disposal	8,250	TON	$ 50	$ 412,500	8,250	TON	$ 50	$ 412,500	8,250	TON	$ 50	$ 412,500
Dredging	79,900	CY	$ 20	$ 1,598,000	99,900	CY	$ 20	$ 1,998,000	119,900	CY	$ 20	$ 2,398,000
Transportation and Disposal (Open Water)	53,933	CY	$ 5	$ 269,663	44,955	CY	$ 5	$ 224,775	26,978	CY	$ 5	$ 134,888
Offload, Transportation and Disposal (Upland)	26,966	TON	$ 60	$ 1,617,975	67,433	TON	$ 60	$ 4,045,950	121,399	TON	$ 60	$ 7,283,925
Debris Screening/Offload/Transport & Dispose	11,985	TON	$ 75	$ 898,875	14,985	TON	$ 75	$ 1,123,875	17,985	TON	$ 75	$ 1,348,875
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500
Purchase & Transport Type II Sand	14,700	TON	$ 8	$ 117,600	14,700	TON	$ 8	$ 117,600	14,700	TON	$ 15	$ 220,500
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	12,200	TON	$ 8	$ 97,600	12,200	TON	$ 8	$ 97,600	12,200	TON	$ 15	$ 183,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 13	$ 182,621
Place Type II and Type III Cap Sand	14,700	TON	$ 5	$ 73,500	14,700	TON	$ 5	$ 73,500	14,700	TON	$ 10	$ 147,000
Place EMNR/Residuals Cover Sand	12,200	TON	$ 5	$ 61,000	12,200	TON	$ 5	$ 61,000	12,200	TON	$ 10	$ 122,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install	-	LF	$ 300	$ -	-	LF	$ 300	$ -	-	LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 7,162,463				$ 10,170,550				$ 15,038,059
Construction Contingency	30	%		$ 2,148,739	30	%		$ 3,051,165	30	%		$ 4,511,418
Total Construction Cost				**$ 9,310,000**				**$ 13,220,000**				**$ 19,550,000**
Project Management	5	%		$ 465,500	5	%		$ 661,000	5	%		$ 977,500
Engineering and Design	10	%		$ 931,000	10	%		$ 1,322,000	10	%		$ 1,955,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 931,000	10	%		$ 1,322,000	10	%		$ 1,955,000
Environmental Monitoring during Construction	21	WEEK	$ 12,500	$ 262,500	26	WEEK	$ 12,500	$ 325,000	30	WEEK	$ 12,500	$ 375,000
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		**$ 465,500**	5	%		**$ 661,000**	5	%		**$ 977,500**
Total Non-Construction Cost				**$ 3,190,500**				**$ 4,426,000**				**$ 6,375,000**
Total Cost				**$ 12,500,000**				**$ 17,650,000**				**$ 25,930,000**

SMA-2 - Dredge and Engineered Cap 2

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000
Demolition												
Dock Demolition (including piles)	36,300	SF	$ 25	$ 907,500	36,300	SF	$ 25	$ 907,500	36,300	25	$ 45	$ 1,633,500
Pile Pulling	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000
Transportation and Disposal	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750
Excavation/Dredging and Disposal												
Upland Excavation	5,500	CY	$ 10	$ 55,000	5,500	CY	$ 10	$ 55,000	5,500	CY	$ 10	$ 55,000
Upland Transportation and Disposal	8,250	TON	$ 50	$ 412,500	8,250	TON	$ 50	$ 412,500	8,250	TON	$ 50	$ 412,500
Dredging	50,200	CY	$ 20	$ 1,004,000	62,800	CY	$ 20	$ 1,256,000	75,300	CY	$ 20	$ 1,506,000
Transportation and Disposal (Open Water)	33,885	CY	$ 5	$ 169,425	28,260	CY	$ 5	$ 141,300	16,943	CY	$ 5	$ 84,713
Offload, Transportation and Disposal (Upland)	16,943	TON	$ 60	$ 1,016,550	42,390	TON	$ 60	$ 2,543,400	76,241	TON	$ 60	$ 4,574,475
Debris Screening/Offload/Transport & Dispose	7,530	TON	$ 75	$ 564,750	9,420	TON	$ 75	$ 706,500	11,295	TON	$ 75	$ 847,125
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500
Purchase & Transport Type II Sand	25,100	TON	$ 8	$ 200,800	14,700	TON	$ 8	$ 117,600	14,700	TON	$ 15	$ 220,500
Purchase & Transport Type III Sand	-	TON	$ -	$ -	41,600	TON	$ 8	$ 332,800	41,600	TON	$ 15	$ 624,000
Purchase & Transport EMNR/Residuals Cover Sand	7,000	TON	$ 8	$ 56,000	7,000	TON	$ 8	$ 56,000	7,000	TON	$ 15	$ 105,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 13	$ 182,621
Place Type II and Type III Cap Sand	25,100	TON	$ 5	$ 125,500	56,300	TON	$ 5	$ 281,500	56,300	TON	$ 10	$ 563,000
Place EMNR/Residuals Cover Sand	7,000	TON	$ 5	$ 35,000	7,000	TON	$ 5	$ 35,000	7,000	TON	$ 10	$ 70,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install	-	LF	$ 300	$ -	-	LF	$ 300	$ -	-	LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 5,600,275				$ 7,898,350				$ 11,794,684
Construction Contingency	30	%		$ 1,680,083	30	%		$ 2,369,505	30	%		$ 3,538,405
Total Construction Cost				**$ 7,280,000**				**$ 10,270,000**				**$ 15,330,000**
Project Management	5	%		$ 364,000	5	%		$ 513,500	5	%		$ 766,500
Engineering and Design	10	%		$ 728,000	10	%		$ 1,027,000	10	%		$ 1,533,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 728,000	10	%		$ 1,027,000	10	%		$ 1,533,000
Environmental Monitoring during Construction	15	WEEK	$ 12,500	$ 187,500	20	WEEK	$ 12,500	$ 250,000	23	WEEK	$ 12,500	$ 287,500
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		**$ 364,000**	5	%		**$ 513,500**	5	%		**$ 766,500**
Total Non-Construction Cost				**$ 2,506,500**				**$ 3,466,000**				**$ 5,021,500**
Total Cost				**$ 9,790,000**				**$ 13,740,000**				**$ 20,350,000**

SMA-2 - Dredge, Engineered Cap & EMNR

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000
Demolition												
Dock Demolition (including piles)	36,300	SF	$ 25	$ 907,500	36,300	SF	$ 25	$ 907,500	36,300	25	$ 45	$ 1,633,500
Pile Pulling	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000
Transportation and Disposal	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750
Excavation/Dredging and Disposal												
Upland Excavation	5,500	CY	$ 10	$ 55,000	5,500	CY	$ 10	$ 55,000	5,500	CY	$ 10	$ 55,000
Upland Transportation and Disposal	8,250	TON	$ 50	$ 412,500	8,250	TON	$ 50	$ 412,500	8,250	TON	$ 50	$ 412,500
Dredging	18,900	CY	$ 20	$ 378,000	23,600	CY	$ 20	$ 472,000	28,400	CY	$ 20	$ 568,000
Transportation and Disposal (Open Water)	12,758	CY	$ 5	$ 63,788	10,620	CY	$ 5	$ 53,100	6,390	CY	$ 5	$ 31,950
Offload, Transportation and Disposal (Upland)	6,379	TON	$ 60	$ 382,725	15,930	TON	$ 60	$ 955,800	28,755	TON	$ 60	$ 1,725,300
Debris Screening/Offload/Transport & Dispose	2,835	TON	$ 75	$ 212,625	3,540	TON	$ 75	$ 265,500	4,260	TON	$ 75	$ 319,500
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500
Purchase & Transport Type II Sand	16,700	TON	$ 8	$ 133,600	-	TON	$ 8	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	66,700	TON	$ 8	$ 533,600	66,700	TON	$ 15	$ 1,000,500
Purchase & Transport EMNR/Residuals Cover Sand	11,400	TON	$ 8	$ 91,200	11,400	TON	$ 8	$ 91,200	11,400	TON	$ 15	$ 171,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 13	$ 182,621
Place Type II and Type III Cap Sand	16,700	TON	$ 5	$ 83,500	66,700	TON	$ 5	$ 333,500	66,700	TON	$ 10	$ 667,000
Place EMNR/Residuals Cover Sand	11,400	TON	$ 5	$ 57,000	11,400	TON	$ 5	$ 57,000	11,400	TON	$ 10	$ 114,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install	-	LF	$ 300	$ -	-	LF	$ 300	$ -	-	LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 3,830,688				$ 5,189,950				$ 7,797,121
Construction Contingency	30	%		$ 1,149,206	30	%		$ 1,556,985	30	%		$ 2,339,136
Total Construction Cost				**$ 4,980,000**				**$ 6,750,000**				**$ 10,140,000**
Project Management	5	%		$ 249,000	5	%		$ 337,500	5	%		$ 507,000
Engineering and Design	10	%		$ 498,000	10	%		$ 675,000	10	%		$ 1,014,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 498,000	10	%		$ 675,000	10	%		$ 1,014,000
Environmental Monitoring during Construction	8	WEEK	$ 12,500	$ 100,000	13	WEEK	$ 12,500	$ 162,500	14	WEEK	$ 12,500	$ 175,000
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		**$ 249,000**	5	%		**$ 337,500**	5	%		**$ 507,000**
Total Non-Construction Cost				**$ 1,729,000**				**$ 2,322,500**				**$ 3,352,000**
Total Cost				**$ 6,710,000**				**$ 9,070,000**				**$ 13,490,000**

SMA-2 - Engineered Cap

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000
Demolition												
Dock Demolition (including piles)	36,300	SF	$ 25	$ 907,500	36,300	SF	$ 25	$ 907,500	36,300	25	$ 45	$ 1,633,500
Pile Pulling	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000
Transportation and Disposal	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750
Excavation/Dredging and Disposal												
Upland Excavation	5,500	CY	$ 10	$ 55,000	5,500	CY	$ 10	$ 55,000	5,500	CY	$ 10	$ 55,000
Upland Transportation and Disposal	8,250	TON	$ 50	$ 412,500	8,250	TON	$ 50	$ 412,500	8,250	TON	$ 50	$ 412,500
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Offload, Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500
Purchase & Transport Type II Sand	36,600	TON	$ 8	$ 292,800	15,100	TON	$ 8	$ 120,800	15,100	TON	$ 15	$ 226,500
Purchase & Transport Type III Sand	-	TON	$ -	$ -	86,200	TON	$ 8	$ 689,600	86,200	TON	$ 15	$ 1,293,000
Purchase & Transport EMNR/Residuals Cover Sand	1,400	TON	$ 8	$ 11,200	1,400	TON	$ 8	$ 11,200	1,400	TON	$ 15	$ 21,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 13	$ 182,621
Place Type II and Type III Cap Sand	36,600	TON	$ 5	$ 183,000	101,300	TON	$ 5	$ 506,500	101,300	TON	$ 10	$ 1,013,000
Place EMNR/Residuals Cover Sand	1,400	TON	$ 5	$ 7,000	1,400	TON	$ 5	$ 7,000	1,400	TON	$ 10	$ 14,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install	-	LF	$ 300	$ -	-	LF	$ 300	$ -	-	LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 2,922,250				$ 3,763,350				$ 5,767,371
Construction Contingency	30	%		$ 876,675	30	%		$ 1,129,005	30	%		$ 1,730,211
Total Construction Cost				**$ 3,800,000**				**$ 4,890,000**				**$ 7,500,000**
Project Management	5	%		$ 190,000	5	%		$ 244,500	5	%		$ 375,000
Engineering and Design	10	%		$ 380,000	10	%		$ 489,000	10	%		$ 750,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 380,000	10	%		$ 489,000	10	%		$ 750,000
Environmental Monitoring during Construction	4	WEEK	$ 12,500	$ 50,000	10	WEEK	$ 12,500	$ 125,000	10	WEEK	$ 12,500	$ 125,000
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		**$ 190,000**	5	%		**$ 244,500**	5	%		**$ 375,000**
Total Non-Construction Cost				**$ 1,325,000**				**$ 1,727,000**				**$ 2,510,000**
Total Cost				**$ 5,130,000**				**$ 6,620,000**				**$ 10,010,000**

SMA-2 - Engineered Cap and EMNR

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000
Demolition												
Dock Demolition (including piles)	36,300	SF	$ 25	$ 907,500	36,300	SF	$ 25	$ 907,500	36,300	25	$ 45	$ 1,633,500
Pile Pulling	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000	580	EA	$ 400	$ 232,000
Transportation and Disposal	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750	1,488	TON	$ 100	$ 148,750
Excavation/Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Offload, Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500	13,700	TON	$ 15	$ 205,500
Purchase & Transport Type II Sand	21,500	TON	$ 8	$ 172,000	-	TON	$ 8	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	86,200	TON	$ 8	$ 689,600	86,200	TON	$ 15	$ 1,293,000
Purchase & Transport EMNR/Residuals Cover Sand	12,400	TON	$ 8	$ 99,200	12,400	TON	$ 8	$ 99,200	12,400	TON	$ 15	$ 186,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 10	$ 137,000	13,700	TON	$ 13	$ 182,621
Place Type II and Type III Cap Sand	21,500	TON	$ 5	$ 107,500	86,200	TON	$ 5	$ 431,000	86,200	TON	$ 10	$ 862,000
Place EMNR/Residuals Cover Sand	12,400	TON	$ 5	$ 62,000	12,400	TON	$ 5	$ 62,000	12,400	TON	$ 10	$ 124,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install	-	LF	$ 300	$ -	-	LF	$ 300	$ -	-	LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 2,401,450				$ 3,242,550				$ 5,197,371
Construction Contingency	30	%		$ 720,435	30	%		$ 972,765	30	%		$ 1,559,211
Total Construction Cost				**$ 3,120,000**				**$ 4,220,000**				**$ 6,760,000**
Project Management	5	%		$ 156,000	5	%		$ 211,000	5	%		$ 338,000
Engineering and Design	10	%		$ 312,000	10	%		$ 422,000	10	%		$ 676,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 312,000	10	%		$ 422,000	10	%		$ 676,000
Environmental Monitoring during Construction	4	WEEK	$ 12,500	$ 50,000	9	WEEK	$ 12,500	$ 112,500	9	WEEK	$ 12,500	$ 112,500
Verification Sampling	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		**$ 156,000**	5	%		**$ 211,000**	5	%		**$ 338,000**
Total Non-Construction Cost				**$ 1,121,000**				**$ 1,513,500**				**$ 2,275,500**
Total Cost				**$ 4,240,000**				**$ 5,730,000**				**$ 9,040,000**

SMA-3 - Dredge

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Demobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Site Preparation for Offloading	1	LS	$ 500,000	$ 500,000	1	LS	$ 500,000	$ 500,000	1	LS	$ 500,000	$ 500,000
Demolition												
Dock Demolition (including piles)	-	SF	$ 25	$ -	-	SF	$ 25	$ -	-	SF	$ 25	$ -
Pile Pulling	-	EA	$ 400	$ -	-	EA	$ 400	$ -	-	EA	$ 400	$ -
Transportation and Disposal	-	TON	$ 100	$ -	-	TON	$ 100	$ -	-	TON	$ 100	$ -
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	373,000	CY	$ 20	$ 7,460,000	466,000	CY	$ 20	$ 9,320,000	559,000	CY	$ 20	$ 11,180,000
Transportation and Disposal (Open Water)	265,763	CY	$ 5	$ 1,328,813	221,350	CY	$ 5	$ 1,106,750	132,763	CY	$ 5	$ 663,813
Transportation and Disposal (Upland)	132,856	TON	$ 60	$ 7,971,375	331,975	TON	$ 60	$ 19,918,500	597,356	TON	$ 60	$ 35,841,375
Debris Screening/Offload/Transport & Dispose	28,000	TON	$ 75	$ 2,100,000	35,000	TON	$ 75	$ 2,625,000	42,000	TON	$ 75	$ 3,150,000
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	93,200	TON	$ 8	$ 745,600	93,200	TON	$ 8	$ 745,600	93,200	TON	$ 15	$ 1,398,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place EMNR/Residuals Cover Sand	93,200	TON	$ 5	$ 466,000	93,200	TON	$ 5	$ 466,000	93,200	TON	$ 10	$ 932,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 20,801,788				$ 34,911,850				$ 53,895,188
Construction Contingency	30	%		$ 6,240,000	30	%		$ 10,470,000	30	%		$ 16,170,000
Total Construction Cost				**$ 27,041,788**				**$ 45,381,850**				**$ 70,065,188**
Project Management	5	%		$ 1,350,000	5	%		$ 2,270,000	5	%		$ 3,500,000
Engineering and Design	10	%		$ 2,700,000	10	%		$ 4,540,000	10	%		$ 7,010,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 2,704,179	10	%		$ 4,538,185	10	%		$ 7,006,519
Environmental Monitoring during Construction	91	WEEK	$ 12,500	$ 1,137,500	111	WEEK	$ 12,500	$ 1,387,500	132	WEEK	$ 12,500	$ 1,650,000
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 1,350,000	5	%		$ 2,270,000	5	%		$ 3,500,000
Total Non-Construction Cost				**$ 9,370,000**				**$ 15,130,000**				**$ 22,790,000**
Total Cost				**$ 36,411,788**				**$ 60,511,850**				**$ 92,855,188**

SMA-3 - Engineered Cap

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Demobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Site Preparation for Offloading	-	LS	$ 500,000	$ -	-	LS	$ 500,000	$ -	-	LS	$ 500,000	$ -
Demolition												
Dock Demolition (including piles)	-	SF	$ 25	$ -	-	SF	$ 25	$ -	-	SF	$ 25	$ -
Pile Pulling	-	EA	$ 400	$ -	-	EA	$ 400	$ -	-	EA	$ 400	$ -
Transportation and Disposal	-	TON	$ 100	$ -	-	TON	$ 100	$ -	-	TON	$ 100	$ -
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	186,300	TON	$ 8	$ 1,490,400	186,300	TON	$ 8	$ 1,490,400	186,300	TON	$ 15	$ 2,794,500
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	186,300	TON	$ 5	$ 931,500	186,300	TON	$ 5	$ 931,500	186,300	TON	$ 10	$ 1,863,000
Place EMNR/Residuals Cover Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 2,651,900				$ 2,651,900				$ 4,887,500
Construction Contingency	30	%		$ 800,000	30	%		$ 800,000	30	%		$ 1,470,000
Total Construction Cost				**$ 3,451,900**				**$ 3,451,900**				**$ 6,357,500**
Project Management	5	%		$ 173,000	5	%		$ 173,000	5	%		$ 318,000
Engineering and Design	10	%		$ 345,000	10	%		$ 345,000	10	%		$ 636,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 345,000	10	%		$ 345,000	10	%		$ 636,000
Environmental Monitoring during Construction	16	WEEK	$ 12,500	$ 200,000	16	WEEK	$ 12,500	$ 200,000	16	WEEK	$ 12,500	$ 200,000
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 173,000	5	%		$ 173,000	5	%		$ 318,000
Total Non-Construction Cost				**$ 1,460,000**				**$ 1,460,000**				**$ 2,330,000**
Total Cost				**$ 4,911,900**				**$ 4,911,900**				**$ 8,687,500**

SMA-3 - EMNR

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Demobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Site Preparation for Offloading	-	LS	$ 500,000	$ -	-	LS	$ 500,000	$ -	-	LS	$ 500,000	$ -
Demolition												
Dock Demolition (including piles)	-	SF	$ 25	$ -	-	SF	$ 25	$ -	-	SF	$ 25	$ -
Pile Pulling	-	EA	$ 400	$ -	-	EA	$ 400	$ -	-	EA	$ 400	$ -
Transportation and Disposal	-	TON	$ 100	$ -	-	TON	$ 100	$ -	-	TON	$ 100	$ -
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	93,200	TON	$ 8	$ 745,600	93,200	TON	$ 8	$ 745,600	93,200	TON	$ 15	$ 1,398,000
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place EMNR/Residuals Cover Sand	93,200	TON	$ 5	$ 466,000	93,200	TON	$ 5	$ 466,000	93,200	TON	$ 10	$ 932,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 1,441,600				$ 1,441,600				$ 2,560,000
Construction Contingency	30	%		$ 430,000	30	%		$ 430,000	30	%		$ 770,000
Total Construction Cost				**$ 1,871,600**				**$ 1,871,600**				**$ 3,330,000**
Project Management	5	%		$ 94,000	5	%		$ 94,000	5	%		$ 167,000
Engineering and Design	10	%		$ 187,000	10	%		$ 187,000	10	%		$ 333,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 187,000	10	%		$ 187,000	10	%		$ 333,000
Environmental Monitoring during Construction	8	WEEK	$ 12,500	$ 100,000	8	WEEK	$ 12,500	$ 100,000	8	WEEK	$ 12,500	$ 100,000
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 94,000	5	%		$ 94,000	5	%		$ 167,000
Total Non-Construction Cost				**$ 890,000**				**$ 890,000**				**$ 1,330,000**
Total Cost				**$ 2,761,600**				**$ 2,761,600**				**$ 4,660,000**

SMA-4 - Dredge

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000	1	LS	$ 200,000	$ 200,000
Demolition												
Dock Demolition (including piles)	3,800	SF	$ 25	$ 95,000	3,800	SF	$ 25	$ 95,000	3,800	SF	$ 25	$ 95,000
Pile Pulling	150	EA	$ 400	$ 60,000	150	EA	$ 400	$ 60,000	150	EA	$ 400	$ 60,000
Transportation and Disposal	150	TON	$ 100	$ 15,000	150	TON	$ 100	$ 15,000	150	TON	$ 100	$ 15,000
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	92,000	CY	$ 20	$ 1,840,000	116,000	CY	$ 20	$ 2,320,000	139,000	CY	$ 20	$ 2,780,000
Transportation and Disposal (Open Water)	65,550	CY	$ 5	$ 327,750	55,100	CY	$ 5	$ 275,500	33,013	CY	$ 5	$ 165,063
Transportation and Disposal (Upland)	32,675	TON	$ 60	$ 1,960,500	82,350	TON	$ 60	$ 4,941,000	148,981	TON	$ 60	$ 8,938,875
Debris Screening/Offload/Transport & Dispose	7,000	TON	$ 75	$ 525,000	9,000	TON	$ 75	$ 675,000	10,000	TON	$ 75	$ 750,000
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	23,100	TON	$ 8	$ 184,800	23,100	TON	$ 8	$ 184,800	23,100	TON	$ 15	$ 346,500
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place EMNR/Residuals Cover Sand	23,100	TON	$ 5	$ 115,500	23,100	TON	$ 5	$ 115,500	23,100	TON	$ 10	$ 231,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 5,453,550				$ 9,011,800				$ 13,711,438
Construction Contingency	30	%		$ 1,640,000	30	%		$ 2,700,000	30	%		$ 4,110,000
Total Construction Cost				**$ 7,093,550**				**$ 11,711,800**				**$ 17,821,438**
Project Management	5	%		$ 350,000	5	%		$ 590,000	5	%		$ 890,000
Engineering and Design	10	%		$ 710,000	10	%		$ 1,170,000	10	%		$ 1,780,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 709,355	10	%		$ 1,171,180	10	%		$ 1,782,144
Environmental Monitoring during Construction	22	WEEK	$ 12,500	$ 275,000	28	WEEK	$ 12,500	$ 350,000	33	WEEK	$ 12,500	$ 412,500
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 350,000	5	%		$ 590,000	5	%		$ 890,000
Total Non-Construction Cost				**$ 2,520,000**				**$ 4,000,000**				**$ 5,880,000**
Total Cost				**$ 9,613,550**				**$ 15,711,800**				**$ 23,701,438**

SMA-4 - Engineered Cap

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	-	LS	$ 200,000	$ -	-	LS	$ 200,000	$ -	-	LS	$ 200,000	$ -
Demolition												
Dock Demolition (including piles)	3,800	SF	$ 25	$ 95,000	3,800	SF	$ 25	$ 95,000	3,800	SF	$ 25	$ 95,000
Pile Pulling	150	EA	$ 400	$ 60,000	150	EA	$ 400	$ 60,000	150	EA	$ 400	$ 60,000
Transportation and Disposal	150	TON	$ 100	$ 15,000	150	TON	$ 100	$ 15,000	150	TON	$ 100	$ 15,000
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	46,200	TON	$ 8	$ 369,600	46,200	TON	$ 8	$ 369,600	46,200	TON	$ 15	$ 693,000
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	46,200	TON	$ 5	$ 231,000	46,200	TON	$ 5	$ 231,000	46,200	TON	$ 10	$ 462,000
Place EMNR/Residuals Cover Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 900,600				$ 900,600				$ 1,455,000
Construction Contingency	30	%		$ 270,000	30	%		$ 270,000	30	%		$ 440,000
Total Construction Cost				**$ 1,170,000**				**$ 1,170,000**				**$ 1,900,000**
Project Management	5	%		$ 59,000	5	%		$ 59,000	5	%		$ 95,000
Engineering and Design	10	%		$ 117,000	10	%		$ 117,000	10	%		$ 190,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 117,000	10	%		$ 117,000	10	%		$ 190,000
Environmental Monitoring during Construction	4	WEEK	$ 12,500	$ 50,000	4	WEEK	$ 12,500	$ 50,000	4	WEEK	$ 12,500	$ 50,000
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 59,000	5	%		$ 59,000	5	%		$ 95,000
Total Non-Construction Cost				**$ 627,000**				**$ 627,000**				**$ 845,000**
Total Cost				**$ 1,797,000**				**$ 1,797,000**				**$ 2,745,000**

Port Gamble Mill Site Marine Area Feasibility Study 7/26/2012

SMA-4 - EMNR

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Demobilization	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Site Preparation for Offloading	-	LS	$ 200,000	$ -	-	LS	$ 200,000	$ -	-	LS	$ 200,000	$ -
Demolition												
Dock Demolition (including piles)	3,800	SF	$ 25	$ 95,000	3,800	SF	$ 25	$ 95,000	3,800	SF	$ 25	$ 95,000
Pile Pulling	150	EA	$ 400	$ 60,000	150	EA	$ 400	$ 60,000	150	EA	$ 400	$ 60,000
Transportation and Disposal	150	TON	$ 100	$ 15,000	150	TON	$ 100	$ 15,000	150	TON	$ 100	$ 15,000
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	23,100	TON	$ 8	$ 184,800	23,100	TON	$ 8	$ 184,800	23,100	TON	$ 15	$ 346,500
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place EMNR/Residuals Cover Sand	23,100	TON	$ 5	$ 115,500	23,100	TON	$ 5	$ 115,500	23,100	TON	$ 10	$ 231,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 600,300				$ 600,300				$ 877,500
Construction Contingency	30	%		$ 180,000	30	%		$ 180,000	30	%		$ 260,000
Total Construction Cost				**$ 780,000**				**$ 780,000**				**$ 1,140,000**
Project Management	5	%		$ 39,000	5	%		$ 39,000	5	%		$ 57,000
Engineering and Design	10	%		$ 78,000	10	%		$ 78,000	10	%		$ 114,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 78,000	10	%		$ 78,000	10	%		$ 114,000
Environmental Monitoring during Construction	2	WEEK	$ 12,500	$ 25,000	2	WEEK	$ 12,500	$ 25,000	2	WEEK	$ 12,500	$ 25,000
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 39,000	5	%		$ 39,000	5	%		$ 57,000
Total Non-Construction Cost				**$ 484,000**				**$ 484,000**				**$ 592,000**
Total Cost				**$ 1,264,000**				**$ 1,264,000**				**$ 1,732,000**

SMA-5 - Dredge

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Demobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Site Preparation for Offloading	1	LS	$ 500,000	$ 500,000	1	LS	$ 500,000	$ 500,000	1	LS	$ 500,000	$ 500,000
Demolition												
Dock Demolition (including piles)	-	SF	$ 25	$ -	-	SF	$ 25	$ -	-	SF	$ 25	$ -
Pile Pulling	-	EA	$ 400	$ -	-	EA	$ 400	$ -	-	EA	$ 400	$ -
Transportation and Disposal	-	TON	$ 100	$ -	-	TON	$ 100	$ -	-	TON	$ 100	$ -
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	952,000	CY	$ 20	$ 19,040,000	1,190,000	CY	$ 20	$ 23,800,000	1,428,000	CY	$ 20	$ 28,560,000
Transportation and Disposal (Open Water)	678,300	CY	$ 5	$ 3,391,500	565,250	CY	$ 5	$ 2,826,250	339,150	CY	$ 5	$ 1,695,750
Transportation and Disposal (Upland)	339,550	TON	$ 60	$ 20,373,000	848,125	TON	$ 60	$ 50,887,500	1,526,275	TON	$ 60	$ 91,576,500
Debris Screening/Offload/Transport & Dispose	71,000	TON	$ 75	$ 5,325,000	89,000	TON	$ 75	$ 6,675,000	107,000	TON	$ 75	$ 8,025,000
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	237,900	TON	$ 8	$ 1,903,200	237,900	TON	$ 8	$ 1,903,200	237,900	TON	$ 15	$ 3,568,500
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place EMNR/Residuals Cover Sand	237,900	TON	$ 5	$ 1,189,500	237,900	TON	$ 5	$ 1,189,500	237,900	TON	$ 10	$ 2,379,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 51,952,200				$ 88,011,450				$ 136,534,750
Construction Contingency	30	%		$ 15,590,000	30	%		$ 26,400,000	30	%		$ 40,960,000
Total Construction Cost				**$ 67,542,200**				**$ 114,411,450**				**$ 177,494,750**
Project Management	5	%		$ 3,380,000	5	%		$ 5,720,000	5	%		$ 8,870,000
Engineering and Design	10	%		$ 6,750,000	10	%		$ 11,440,000	10	%		$ 17,750,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 6,754,220	10	%		$ 11,441,145	10	%		$ 17,749,475
Environmental Monitoring during Construction	231	WEEK	$ 12,500	$ 2,887,500	284	WEEK	$ 12,500	$ 3,550,000	337	WEEK	$ 12,500	$ 4,212,500
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000	1	LS	$ 50,000	$ 50,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 3,380,000	5	%		$ 5,720,000	5	%		$ 8,870,000
Total Non-Construction Cost				**$ 23,280,000**				**$ 38,000,000**				**$ 57,580,000**
Total Cost				**$ 90,822,200**				**$ 152,411,450**				**$ 235,074,750**

SMA-5 - Engineered Cap

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Demobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Site Preparation for Offloading	-	LS	$ 500,000	$ -	-	LS	$ 500,000	$ -	-	LS	$ 500,000	$ -
Demolition												
Dock Demolition (including piles)	-	SF	$ 25	$ -	-	SF	$ 25	$ -	-	SF	$ 25	$ -
Pile Pulling	-	EA	$ 400	$ -	-	EA	$ 400	$ -	-	EA	$ 400	$ -
Transportation and Disposal	-	TON	$ 100	$ -	-	TON	$ 100	$ -	-	TON	$ 100	$ -
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	475,900	TON	$ 8	$ 3,807,200	475,900	TON	$ 8	$ 3,807,200	475,900	TON	$ 15	$ 7,138,500
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	475,900	TON	$ 5	$ 2,379,500	475,900	TON	$ 5	$ 2,379,500	475,900	TON	$ 10	$ 4,759,000
Place EMNR/Residuals Cover Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 6,416,700				$ 6,416,700				$ 12,127,500
Construction Contingency	30	%		$ 1,930,000	30	%		$ 1,930,000	30	%		$ 3,640,000
Total Construction Cost				**$ 8,346,700**				**$ 8,346,700**				**$ 15,767,500**
Project Management	5	%		$ 417,000	5	%		$ 417,000	5	%		$ 788,000
Engineering and Design	10	%		$ 835,000	10	%		$ 835,000	10	%		$ 1,577,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 835,000	10	%		$ 835,000	10	%		$ 1,577,000
Environmental Monitoring during Construction	40	WEEK	$ 12,500	$ 500,000	40	WEEK	$ 12,500	$ 500,000	40	WEEK	$ 12,500	$ 500,000
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 417,000	5	%		$ 417,000	5	%		$ 788,000
Total Non-Construction Cost				**$ 3,230,000**				**$ 3,230,000**				**$ 5,460,000**
Total Cost				**$ 11,576,700**				**$ 11,576,700**				**$ 21,227,500**

SMA-5 - EMNR

	LOW END				BEST PROFESSIONAL JUDGMENT				HIGH END			
Item	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**	**Amount**	**Units**	**Unit Cost**	**Total Cost**
Mobilization and Demobilization												
Mobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Demobilization	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000	1	LS	$ 100,000	$ 100,000
Site Preparation for Offloading	-	LS	$ 500,000	$ -	-	LS	$ 500,000	$ -	-	LS	$ 500,000	$ -
Demolition												
Dock Demolition (including piles)	-	SF	$ 25	$ -	-	SF	$ 25	$ -	-	SF	$ 25	$ -
Pile Pulling	-	EA	$ 400	$ -	-	EA	$ 400	$ -	-	EA	$ 400	$ -
Transportation and Disposal	-	TON	$ 100	$ -	-	TON	$ 100	$ -	-	TON	$ 100	$ -
Dredging and Disposal												
Upland Excavation	-	CY	$ 10	$ -	-	CY	$ 10	$ -	-	CY	$ 10	$ -
Upland Transportation and Disposal	-	TON	$ 50	$ -	-	TON	$ 50	$ -	-	TON	$ 50	$ -
Dredging	-	CY	$ 20	$ -	-	CY	$ 20	$ -	-	CY	$ 20	$ -
Transportation and Disposal (Open Water)	-	CY	$ 5	$ -	-	CY	$ 5	$ -	-	CY	$ 5	$ -
Transportation and Disposal (Upland)	-	TON	$ 60	$ -	-	TON	$ 60	$ -	-	TON	$ 60	$ -
Debris Screening/Offload/Transport & Dispose	-	TON	$ 75	$ -	-	TON	$ 75	$ -	-	TON	$ 75	$ -
Capping/Cover												
Purchase & Transport Type I Cap Sand & Gravel	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 15	$ -
Purchase & Transport Type II Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport Type III Sand	-	TON	$ -	$ -	-	TON	$ -	$ -	-	TON	$ 15	$ -
Purchase & Transport EMNR/Residuals Cover Sand	237,900	TON	$ 8	$ 1,903,200	237,900	TON	$ 8	$ 1,903,200	237,900	TON	$ 15	$ 3,568,500
Purchase & Transport Armor Material	-	TON	$ 25	$ -	-	TON	$ 25	$ -	-	TON	$ 25	$ -
Place Type I Cap Sand & Gravel	-	TON	$ 10	$ -	-	TON	$ 10	$ -	-	TON	$ 13	$ -
Place Type II and Type III Cap Sand	-	TON	$ 5	$ -	-	TON	$ 5	$ -	-	TON	$ 10	$ -
Place EMNR/Residuals Cover Sand	237,900	TON	$ 5	$ 1,189,500	237,900	TON	$ 5	$ 1,189,500	237,900	TON	$ 10	$ 2,379,000
Place Armor Material	-	TON	$ 15	$ -	-	TON	$ 15	$ -	-	TON	$ 20	$ -
Sheet Pile Wall												
Sheet Pile Provide and Install		LF	$ 300	$ -		LF	$ 300	$ -		LF	$ 300	$ -
Eelgrass planting	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -	-	ACRE	$ 50,000	$ -
Environmental Controls	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000	1	LS	$ 10,000	$ 10,000
Bathymetric Surveys	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000	2	EA	$ 10,000	$ 20,000
Subtotal Construction Costs				$ 3,322,700				$ 3,322,700				$ 6,177,500
Construction Contingency	30	%		$ 1,000,000	30	%		$ 1,000,000	30	%		$ 1,850,000
Total Construction Cost				**$ 4,322,700**				**$ 4,322,700**				**$ 8,027,500**
Project Management	5	%		$ 216,000	5	%		$ 216,000	5	%		$ 401,000
Engineering and Design	10	%		$ 432,000	10	%		$ 432,000	10	%		$ 803,000
Permitting	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000	1	LS	$ 75,000	$ 75,000
Construction Management	10	%		$ 432,000	10	%		$ 432,000	10	%		$ 803,000
Environmental Monitoring during Construction	20	WEEK	$ 12,500	$ 250,000	20	WEEK	$ 12,500	$ 250,000	20	WEEK	$ 12,500	$ 250,000
Verification Sampling	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -	0	LS	$ 10,000	$ -
Long Term Monitoring	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000	5	LS	$ 30,000	$ 150,000
Mitigation	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -	0	LS	$ 50,000	$ -
Ecology Oversight Costs	5	%		$ 216,000	5	%		$ 216,000	5	%		$ 401,000
Total Non-Construction Cost				**$ 1,770,000**				**$ 1,770,000**				**$ 2,880,000**

Total Cost				**$ 6,092,700**				**$ 6,092,700**				**$ 10,907,500**