

SEDIMENT INVESTIGATION REPORT

Oakland Bay Sediment Characterization Study, Mason County, Washington



Prepared for

Washington Department of Ecology
Toxics Cleanup Program
Southwest Regional Office

November 2010

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Washington Department of Ecology
Toxics Cleanup Program
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Abbreviations and Acronyms

BEHP	bis(2-ethylhexyl) phthalate
cm	centimeter
COC	chain of custody
COPC	Constituents of Potential Concern
CSL	cleanup screening level
CV	coefficient of variation
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DGPS	Differential Global Positioning System
DMMP	Dredged Material Management Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
GPS	global positioning system
HpCDD	heptachlorodibenzo-p-dioxin
HpCDF	heptachlorodibenzo-furan
Herrera	Herrera Environmental Consultants, Inc.
HPAH	high molecular weight polycyclic aromatic hydrocarbons
kg	kilogram
kHz	kilohertz
LAET	lowest apparent effects threshold
LC50	median lethal concentration
LPAH	low molecular weight polycyclic aromatic hydrocarbon
MDL	method detection limit
µg	microgram
mg	milligram
MLLW	mean lower low water

MS/MSD	matrix spike / matrix spike duplicate
MSDS	material safety data sheet
NAD 83	North American Datum of 1983
OC	organic carbon
OCDD	octachlorodibenzo-p-dioxin
OCDF	octachlorodibenzo-furan
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
ppt	parts per thousand
PQL	practical quantitation limit
PSEP	Puget Sound Estuary Program
SMS	Sediment Management Standards
SQS	Sediment Quality Standard
SVOC	semi-volatile organic compound
TBT	tributyltin
TEQ	toxic equivalent
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TVS	total volatile solids
USCS	Unified Soil Classification System
USEPA	U.S. Environmental Protection Agency
WAC	Washington Administrative Code
WWTP	wastewater treatment plant

Executive Summary

Puget Sound is a unique ecosystem and an economically important natural resource for the state of Washington. In 2006, the state approved legislation that provides substantial funding for the Puget Sound Initiative (PSI) for restoration and recovery of Puget Sound by the year 2020. In response to this initiative, the Department of Ecology Toxics Cleanup Program is focusing on cleanup and restoration of in-water and upland sites within 0.5 mile of Puget Sound.

As part of the PSI, Ecology identified Oakland Bay as one of seven high priority areas in Puget Sound for cleanup and restoration because of its important habitat and valuable natural resources. Ecology conducted the Oakland Bay Sediment Study to identify potential areas of sediment contamination and confirm priority areas for cleanup and restoration in the bay and surrounding area. Ecology designed this study to provide overall sediment quality information, determine the nature and extent of sediment contamination, and help develop protective cleanup levels.

The Oakland Bay study area included the bay itself plus Shelton Harbor and the entrance to Hammersley Inlet. The study included an assessment of sediment input and transport throughout the bay system and collection of sediment samples for both chemical and biological (toxicity) analyses.

A geomorphic assessment of the Oakland Bay system was conducted to evaluate sediment input processes to the bay and both sedimentation and sediment transport process within the bay. The assessment included:

- A general review of geological processes leading to the physical structure of the near-surface environment
- Geophysical surveys using several acoustic and resistivity methods
- Sediment core logging to determine lithology across the bay
- Radioisotope dating of core samples to evaluate sedimentation rates

Sediment transport processes were used to develop a model of wood waste distribution across the study area.

Fifty surface grab and 51 subsurface core samples were collected across the study area; additionally, three reference sediment surface grab samples were collected from Carr Inlet to provide chemical and toxicity background comparisons, located approximately 20 miles (32 kilometers) to the east. Samples were analyzed to evaluate the potential presence of chemicals associated with industrial activities and with decaying wood, and to evaluate the deposition rate of sediment across the Oakland Bay study area through radioisotope dating. Surface grab samples were collected at every sampling location, except radioisotope core locations, and were visually inspected for wood content, analyzed for chemical constituents, and

analyzed for biological toxicity (bioassay). Samples collected at designated wood waste locations were analyzed for wood waste constituents in addition to standard industrial chemicals of concern. All surface grab samples were analyzed for dioxins and furans.

Subsurface core samples were collected at most surface sampling locations, separated into 1 foot (0.3 meter) lengths, visually inspected for wood content, and then each core section from the 1-2 foot depth interval was analyzed for chemical constituents; all other 1 foot (0.3 meter) core sections were frozen and archived for possible future analysis. Samples collected at designated wood waste locations were analyzed for wood waste constituents in addition to standard industrial chemicals of concern. Selected 1-2 foot core sections were analyzed for dioxins and furans based on surface analytical results. Three designated cores were analyzed for lead-210 and cesium-137 analysis to aid in determining sedimentation rates across the study area.

Chemical fingerprinting analysis was conducted on dioxin/furan data comparing Oakland Bay study results with standard source chemical profiles, another nearby area of known dioxin/furan release, and area-wide background profiles.

Sampling and analysis results indicate that industrial contaminants of concern were found below Ecology's Sediment Management Standards screening levels across the study area (except for one chemical at one location). Dioxins/furans, which are not addressed in the Sediment Management Standards, were found at relatively high concentrations across the entire study area, indicating probable local source(s). Toxicity test failures were found throughout Shelton Harbor and Oakland Bay, but not in Hammersley Inlet. It is likely that these failures resulted from conditions associated with the presence of wood waste, fine-grain sediment, synergistic effects of these and other correlated constituents of concern, or some unmeasured condition.

1.0 Introduction

Oakland Bay is one of seven bays identified as a priority for environmental cleanup by the Department of Ecology (Ecology) as part of the Toxics Cleanup Program's Puget Sound Initiative. Bays were selected for cleanup where early actions would provide the highest beneficial results for restoration of habitat, protection and restoration of natural resources, and protection of environmental and human health. Ecology identified Oakland Bay for a focused sediment investigation related to source control, sediment cleanup, and restoration.

Ecology initiated this sediment investigation because previous environmental investigations throughout the bay, including the Shelton Harbor area, documented presence of wood waste and contamination from historical or current industrial and commercial activities. Previous sediment quality investigations indicated that contaminant concentrations exceeded Chapter 173-204 Washington Administrative Code (WAC) Sediment Management Standards (SMS) and that areas with high concentrations of wood waste were present. Bioassays were recommended for wood waste assessment and in areas where SMS criteria were exceeded (Ecology 2000).

Ecology's Toxics Cleanup Program is in the process of identifying contaminated sites within 0.5 mile of Puget Sound. The bay-wide (rather than site-specific) approach was developed to prioritize cleanup of numerous sites within a geographic area. This study focused on marine sediment characterization across Oakland Bay, emphasizing locations associated with specific upland inputs to the bay and wood deposition from rafting and wood chip processing operations.

Ecology directed this sediment investigation to support the prioritization of cleanup and restoration actions under the Puget Sound Initiative. To meet these objectives, Herrera Environmental Consultants, Inc. (Herrera) supported project planning and conducted field sampling as a subcontractor to Ecology and Environment, Inc. under contract to Ecology. As prime contractor, Ecology and Environment provided technical coordination with Ecology and oversight of all work products.

1.1 Study Area

The Oakland Bay system is a shallow estuary located in South Puget Sound, with the City of Shelton and its industrial waterfront and harbor located to the southwest (Figures 1-1 and 1-2). Water depth ranges between 10 and 35 feet, with shallow and broad intertidal zones exposed during low tides at the north end of the bay and in Shelton Harbor. Due to the restrictive nature of Hammersley Inlet, a long narrow waterway linking the bay to the Puget Sound Basin, the water in Oakland Bay has high refluxing, low flushing, and high retention rates (Ecology 2004a). Eight major freshwater creeks discharge into the bay and harbor:

- Deer
- Cranberry
- Malaney

- Uncle John
- Campbell
- Johns
- Shelton
- Goldsborough

The waters of Shelton Harbor and the northern portions of Oakland Bay are currently listed as impaired by the state of Washington under Section 303(d) of the Clean Water Act because of fecal coliform bacteria levels (Ecology 2004b).

The Shelton waterfront and harbor are currently (and were historically) used by several timber and wood product manufacturing industries, including saw mills and plywood manufacturing, pulp and paper production, and insulation board and fiberboard manufacturing. Over time, process chemicals and wastewater from wood-product manufacturing processes have either been discharged (through onsite industrial stormwater systems) or released (due to accidental spills and leaks to the harbor) to Shelton and Goldsborough Creeks, or across upland portions of the waterfront. Discharges and spills of process chemicals and wastewater have included:

- Release of process wastewater discharges and sulfite waste liquor generated from the former Rayonier pulp mill
- Release of air emission particulates from wood-fired power plants and associated emission stacks
- Power plant baghouse solids
- Laboratory chemicals
- Wood preservatives containing chlorinated phenols
- Numerous releases of petroleum products, polychlorinated biphenyl (PCB)-contaminated oil, and resin and veneer wastewater

In addition, wood waste has been released directly into the bay through chip loading, log rafts, and log transfer operations.

The Squaxin Island Tribe has harvested shellfish from Oakland Bay for centuries. Commercial shellfish harvesting has been important since the 1880s (Kenny 2007). Pollution associated with sulfite waste liquor discharged by the Rayonier pulp mill is believed to have led to declining commercial oyster production by the mid-1940s (Shaffer 2003). Repopulation of oysters and other shellfish in the northern portions of Oakland Bay, including Chapman Cove, and development of a second-generation of shellfish production began in the late 1960s.

Fecal coliform contamination from excessive inflow and infiltration to the city's aging sewer and stormwater collection systems, onsite septic systems, and surface water runoff from small farms have contributed to recent closures of shellfish harvesting in portions of the bay. A Shellfish Protection District was created by Mason County in 2007 in response to shellfish harvest



Figure 1-1. Vicinity map of Oakland Bay, Mason County, Washington.

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Figure 1-2. Site map of Shelton Harbor, Shelton, Washington.

restrictions placed on the north end of Oakland Bay by the Washington State Department of Health (Figure 1-1). A coordinated, multi-party strategy was developed to address fecal coliform bacteria, and is currently implemented by the Mason County Clean Water District.

Land use adjacent to Oakland Bay consists of rural residential, commercial forest, and agricultural, with some industrial and commercial development along the west and south sides of the bay. Approximately 100 small farms are located within the watershed (Berbells 2003). Septic systems are used to treat waste throughout most of the study area.

1.2 Previous Investigations

Over the past 20 years, sediment and water quality investigations have focused on specific contaminant releases and general bay-wide conditions. A detailed review of studies conducted in Shelton Harbor and across Oakland Bay is provided in the *Final Summary of Existing Information and Identification of Data Gaps Technical Memorandum* (Herrera 2008a), developed to support project planning and summarized in the *Sampling and Analysis Plan* (Herrera 2008b). The following studies were reviewed:

- Initial Investigation of the Simpson Marine Railway (Ecology 2005)
- Remedial Investigation of the Evergreen Fuel Site (Farallon 2005)
- Ecology Reconnaissance Survey of Inner Shelton Harbor Sediments (Ecology 2000)
- 1997-1999 PSAMPNOAA (Puget Sound Assessment and Monitoring Program and the National Oceanographic and Atmospheric Administration [NOAA] National Status and Trends Program)
- 1992 DNRREC92 (Washington DNR Aquatic Lands Sediment Quality Reconnaissance)
- City of Shelton Storm Drain Sediment Study (Ecology 1990)
- 1989-1995 PSAMP HP (Puget Sound Assessment and Monitoring Program's historical sediment monitoring)
- U.S. Environmental Protection Agency (USEPA) National Dioxin Study, Final Dioxin Study Report – Simpson Timber Company (CH2M Hill 1987)

1.3 Goals and Objectives

The general objective of the study was to conduct a multi-faceted, tiered sediment characterization of Oakland Bay to define the bay-wide nature and extent of potential sediment

contamination, including wood waste. Sediment characterization was necessary to identify areas of concern, prioritize areas for cleanup and restoration, and identify potential sources of contamination. Water quality conditions, including fecal coliform contamination, were not part of this investigation. Specific objectives of the sediment characterization included the following:

- In Shelton Harbor, conduct a sampling and analysis effort based on previous investigations and existing data gaps to further characterize and prioritize areas for potential cleanup.
- In Oakland Bay, assess presence of contaminants and wood waste at locations associated with creek inputs, potential shoreline sources, and areas of historic wood rafting.
- Evaluate potential for transport of contaminated sediments and wood waste out of Shelton Harbor into and across Oakland Bay and Hammersley Inlet.
- Conduct a geophysical survey to determine the distribution of wood waste across Shelton Harbor and Oakland Bay for mapping and determining volume estimates.
- Characterize horizontal and vertical extent of contamination in sediment across Shelton Harbor for effects from known and suspected sources, and characterize potential transport into Oakland Bay.
- Characterize wood waste using chemical and toxicity testing.
- Estimate sedimentation rates in Oakland Bay and Shelton Harbor using radioisotope dating and geophysical survey data.
- Conduct bioassays to determine extent of acute and chronic toxicity of sediment at all surface locations in Shelton Harbor and Oakland Bay.
- Conduct a screening-level "fingerprinting" evaluation of total petroleum hydrocarbons (TPH), polynuclear aromatic hydrocarbons (PAHs), and dioxins/furans sediment data to attempt differentiation between sources of contaminants.
- Provide chemical and toxicity testing comparisons through analysis of sediments from a reference location.

1.4 Study Design

The study followed methods and guidance developed in the following state sediment management programs:

- Sediment Management Standards (173-204 WAC)
- Sediment Sampling and Analysis Plan Appendix (Ecology 2008)
- Puget Sound Estuary Program (PSEP)
- Dredge Materials Management Program (DMMP)

The *Final Summary of Existing Information and Identification of Data Gaps Technical Memorandum* (Herrera 2008b) identified six major issues of concern at Oakland Bay to be addressed in this investigation, including:

1. The spatial extent and contaminant concentration of wood waste debris associated with pulp, paper, and lumber mill activities, including log rafting
2. Petroleum contamination in areas associated with petroleum-based industry, and machinery and vehicles associated with timber processing, boating, and stormwater runoff from roads
3. Contaminants of potential concern (COPC) concentrations in sediment near industrial discharge points along the Shelton Harbor shoreline
4. COPC concentrations in sediment near creek discharge points
5. Tributyltins (TBT) contamination in sediment near the marina and former marine railway
6. Semivolatile organic compound (SVOC) concentrations associated with dense areas of intact, degrading, and/or submerged creosote pilings

Sample stations were located to address each of these issues.

Sampling locations were modified and the original risk assessment and tissue sampling removed (to be conducted in the future, if necessary) based on input from citizens at public meetings and technical meetings held with stakeholders and interested agencies. Sampling areas are summarized in Table 1-1.

Table 1-1. Description of study sampling areas.

Areas of Concern	Location	Potential Sources of Interest
Oakland Bay	Northeast and central Oakland Bay	Six creeks, three bulk fuel facilities, two gas stations, a wood preservative site, log rafts
Shelton Harbor	West of Oakland Bay and Hammersley Inlet	Two creeks, numerous stormwater and industrial waste pipe discharges, overland flow from industrial operations, fuel spills, groundwater, historic wood treating, log rafting, wood chip loading
Hammersley Inlet	Southeast portion of Oakland Bay and Hammersley Inlet to Miller Point	WWTP effluent discharges, log rafts, sediment redistribution from Shelton Harbor
Reference Samples	Carr Inlet	Reference sediment for toxicity testing

Sediment samples were collected across Shelton Harbor, Oakland Bay, and Hammersley Inlet to identify the presence of contaminants of potential concern (COPCs), to estimate the abundance of wood waste, and to evaluate accumulation rates. Samples were collected from stations associated with historical industrial waste discharges to the marine environment, along shorelines and from areas across each water body where wood waste has been directly deposited, where aerial deposition has or is likely to have occurred, or where contaminants may have been redistributed by tides and currents.

Some sampling locations are referred to as sediment sample locations and others are described as wood waste sample locations (specific locations are discussed in Section 3.5.2). This distinction is made to identify specific locations known or suspected to be impacted by the release of wood waste to the native sediment from documented historical activities or from seabed characteristics found during the geophysical survey. Samples at wood waste stations were analyzed for wood waste constituents in addition to the industrial chemical suite. Sediment sampling stations were assigned to areas where the sediment was not expected to have been significantly impacted by wood waste.

The final sampling and analysis plan for the study included 53 sediment and wood waste sample stations in the study area, three stations within the study area for radiological dating analysis, and three reference sample stations in Carr Inlet. Some of the planned samples could not be collected due to obstructions encountered in the field (surface samples could not be collected at stations HI-1, SH-6, and SH-8, and core samples could not be collected at stations HI-5, SH-3, SH-6, SH-24, and SH-25 – refer to Section 3.5.2). Fifty surface samples and 48 cores were obtained for chemical analysis. The three reference samples and three radiological cores were successfully collected.

Samples were collected from the sediment surface 0 to 4 inches (0 to 10 centimeters [cm]), from 4 foot cores (1.2 meters), and from 10 to 12 foot cores (3.1 to 3.7 meters) at some wood waste locations. Core depths were limited by sediment composition and the degree to which sample collection equipment could penetrate the wood waste or sediment. Field personnel removed larger, obvious wood waste materials (e.g., large pieces of bark or solid wood chips) from each sample before submitting aliquots for analysis; wood fines (e.g., fibers and sawdust) were not removed from the samples. A visual estimate of gross wood content was made during sample processing and recorded in notebooks. Bioassays were conducted on all surface sediment samples collected.

A consistent suite of industrial COPCs was analyzed in all surface samples, all 1-2 foot core sections collected from Shelton Harbor, and the 1-2 foot core sections in the three wood waste cores collected from Oakland Bay. This suite included PCBs as Aroclors, SVOCs, organochlorine pesticides, and heavy metals. Dioxins/furans were analyzed in all surface samples and in the 1-2 foot core sections from Shelton Harbor. TBTs and petroleum hydrocarbons were analyzed at select locations. Total organic (TOC), grain size, sulfide, and ammonia analyses were conducted at all locations to supplement industrial COPC data. Wood waste COPCs included total volatile solids (TVS), resin acids, and guaiacols (tested only at designated wood waste stations). Selected archived samples were later tested for dioxin at depth, and for resin acids in surface sediments.

Study design elements described above are summarized for each portion of the study area below:

- Oakland Bay: 14 surface and core sediment stations; three surface and core wood waste stations; and two radiological core stations:
 - All surface sediment and wood waste station samples were tested for industrial COPCs (SVOCs, pesticides, PCB Aroclors, and heavy metals) and dioxins/furans; select surface samples were additionally tested for petroleum hydrocarbons.
 - The 1-2 foot core depth at three wood waste station samples were analyzed for industrial COPCs (SVOCs, pesticides, PCB Aroclors, and heavy metals); surface and 1-2 foot core depth samples were tested for resin acids, guaiacols, and TVS.
 - All surface and 1-2 foot depth samples were tested for TOC, grain size, sulfides, and ammonia.
 - Archived surface sediment samples at several locations were tested for resin acids (OB-2, OB-5, OB-6, OB-10, OB-12, OB-13).
 - Archived 1-2 foot core section samples from several locations were tested for dioxins/furans (OB-3, OB-6, OB-9, OB-10, OB-12).
 - Two sets of radiological station samples were tested for lead-210 and cesium-137.
 - All surface station samples were subjected to bioassay testing.
- Shelton Harbor: 14 sediment and 13 wood waste surface stations; 14 sediment and 11 wood waste core stations; and 1 radiological station:
 - All surface (0-10 cm) and 1-2 foot core section samples at wood waste stations were tested for industrial COPCs (SVOCs, pesticides, PCB Aroclors, and heavy metals) and surface samples were tested for dioxins/furans; select surface and subsurface samples were also tested for petroleum hydrocarbons and TBTs.
 - All surface and 1-2 foot core section samples at wood waste stations were tested at for resin acids, guaiacols, and TVS.
 - All surface and 1-2 foot depth samples were tested for TOC, grain size, sulfides, and ammonia.
 - Archived 2-3 foot core sections at selected locations were tested for dioxins/furans (SH-2, SH-4, SH-9, SH-10, SH-12, SH-13,

- SH-14); selected 1-2 foot core sections also were analyzed for dioxins/furans (SH-12 and SH-13).
- One set of radiological station samples was tested for lead-210.
- All surface stations were subjected to bioassay testing.
- Hammersley Inlet: Six sediment surface stations, six sediment core stations, no wood waste stations, and no radiological stations:
 - All surface (0-10 cm) sediment stations were tested for industrial COPCs (SVOCs, pesticides, PCB Aroclors, and heavy metals) and dioxins/furans.
 - All samples were tested for TOC, grain size, sulfides, and ammonia.
 - Archived surface samples at selected locations were tested for resin acids (HI-1, HI-2, HI-4).

1.5 How This Report is Organized

The remainder of this document discusses the methods and results from the sediment investigation, and is organized as follows:

- **Section 2:** A brief summary of existing information
- **Section 3:** Describes the geophysical, sampling, and analytical methods used to complete the scope of work
- **Section 4:** Presents the geophysical study results, laboratory analytical results (including data validation considerations), and field sample descriptions
- **Section 5:** Provides an interpretation of data, describing sediment transport and the distribution of chemical compounds and wood waste in surface and subsurface sediments, and associated bioassay toxicity results
- **Section 6:** Discusses fingerprinting analysis performed on petroleum hydrocarbons, PAHs, and dioxins and furans
- **Section 7:** Discusses sediment quality trends across the study area
- **Section 8:** Presents conclusions and recommendations drawn from the study

2.0 Summary of Existing Information

2.1 Potential Sources of Contamination

Discharges and spills of process chemicals and wastewater from wood processing activities conducted along the Shelton Harbor waterfront have included the following (see Figure 1-2):

- Release of process wastewaters and sulfite waste liquor generated from the former Rayonier pulp mill between the mid-1920s through late 1950s
- Release of air emission particulates from wood-fired (hog fuel) power plants and associated emission stacks operating without air emissions control from Simpson and Rayonier mills along the south and west shores of Shelton Harbor between the mid-1920s and the late 1950s and Simpson's main power plant and its associated stacks that continued operating without emission control until 1976, when baghouses were installed
- Release of air emission particulates from the pulp mill burn plant located on the hillside above the mill used to dispose of spent waste liquor
- Residues from baghouses at the Simpson hog fuel power plant were mixed into slurries and discharged to both the former wastewater treatment plant (WWTP) on Pine Street (1976 to 1979) and to the existing plant at Eagle Point (1979 to 1984); WWTP effluent was discharged at two locations immediately beyond the harbor limits
- Various chemicals used at a former ITT Rayonier Research Laboratory specializing in cellulose chemistry and silvichemicals produced from wood pulp were discharged to the harbor through the laboratory industrial stormwater discharge system from the mid-1930s to the mid-1990s
- A wood preservative dip tank (location unknown) was referred to in a 1981 Ecology file. A letter stated that approximately 9,400 gallons of dilute Permatox 200 wood preservative was removed and disposed of by spraying it across the Simpson Dayton dry log sort yard. According to a material safety data sheet (MSDS), the preservative contained chlorinated phenols and pentachlorophenol (PCP).
- Residual Bunker C fuel oil in soil and groundwater from leaking aboveground storage tanks previously located between Sawmill #3 and Goldsborough Creek were identified in 1991. Limited removal of contaminated soil was conducted; however, residual contamination was

left in place along Goldsborough Creek, the railroad tracks, and a metal frame tower. An Agreed Order was established for cleanup of the site in 2007.

- Numerous spill incidents reportedly occurred between 1980 and 2004. Most of the reported spills were petroleum products, including hydraulic oil, soluble or biodegradable lube oil, gear oil, and diesel. Other reported spills included PCB-contaminated oil next to the railroad roundhouse in 1984; resin and veneer wastewater discharged to Shelton Creek in 1987 and 1988; and waste oil contaminated with PCBs adjacent to the plywood plant near Shelton Creek in 1990.

Since the mid-1920s, numerous pilings treated with wood preservatives (e.g., creosote, PCP, metals) have been installed in the harbor to support over-water railroad spurs used for unloading logs from trains directly into the water, to stabilize log rafts, and for shoreline bulkheads.

Logs used in lumber, plywood, and fiberboard manufacturing were rafted and stored in the water before processing at sawmills and plywood plants from the late 1800s through the 1990s. Log rafting activities have continued to the present in Shelton Harbor, including the Simpson log truck unloading facility at the north end of the harbor next to the vessel haul-out and marine railway facility (at the end of the Pine Street right of way) and along the south shore of the harbor adjacent to the Manke log sorting yard. A heavy build-up of wood waste was identified at the chip barge loading area at the Simpson sawmill in the *Reconnaissance Survey of Inner Shelton Harbor Sediments* (Ecology 2000).

From the early 1900s to late 2005, a bulk fuel storage marine facility operated at the north end of Shelton Harbor (also known as the former Evergreen Fuel site; see Figure 1-2). In addition to Evergreen Fuel, three bulk fuel storage marine facilities operated about a half mile northeast of Shelton along the west shore of Oakland Bay (Union Oil, Shell, and ARCO) from the early 1930s to the mid-1980s (Figure 1-1).

TBTs, used as an anti-fouling agent on boat bottoms, have been found in sediments collected adjacent to the former Simpson marine railway. The presence of TBTs in sediment is likely due to historical and current activities, such as sandblasting, cleaning, and painting of boat bottoms conducted in the vicinity of the Shelton Marina.

Shelton Harbor has received discharges from the city's former and existing WWTP outfalls, septic systems, timber industries, commercial businesses, and residential communities, and non-point source runoff from stormwater since the early 1900s. The harbor also receives direct surface water discharge from Shelton and Goldsborough Creeks, both of which flow through and have received industrial stormwater runoff from the Simpson waterfront plant since the early 1940s.

Other sites identified as potential sources of contamination located at a distance from Shelton Harbor and near Oakland Bay or adjacent to creeks that drain into the bay (see Figure 1-1) include:

- Two gasoline service stations operating since the early 1970s, including one station located along SR 3 adjacent to Johns Creek (Bayshore Union 76 gas station) and the other approximately 2,300 feet (700 meters) northeast of the Oakland Bay shoreline (Deer Creek store). Gasoline contamination in soil and groundwater was identified at the Deer Creek station.
- A concrete dip tank that previously contained wood preservatives for treating fence posts was identified at the Calvin J. Moran property adjacent to the bay. The concrete tank has reportedly overflowed during periods of heavy rainfall since last used in 1960.

2.2 Chemicals of Potential Concern

COPCs to Oakland Bay sediments and biota were identified based on known chemical associations with historic and current land uses and activities, and from earlier sediment investigations conducted within the study area. The following chemicals were identified as COPCs, some of which have Washington State SMS criteria:

- Conventional analytes, including ammonia, total sulfides, TOC, and TVS
- Polychlorinated dibenzo-p-dioxins (dioxins) and polychlorinated dibenzofurans (furans)
- PCBs
- Chlorinated pesticides
- SVOCs, including PAHs, phenols, PCP, cresols, and phthalates
- Resin acids and guaiacols
- TBTs
- Heavy metals
- Petroleum products (gasoline-, diesel-, and lube oil-range hydrocarbons)

Many of these chemicals are known to be persistent in the environment as potentially bioaccumulative, and toxic, including dioxins/furans, PCBs, and PAHs. In addition, wood waste is created by deposition of bark, wood chunks, wood chips, and sawdust within the marine environment. These wood products decay over time and can have a variety of physical and chemical adverse impacts on aquatic life, including:

- Organic enrichment of sediments
- Oxygen depletion in the water column

- Alteration of benthic communities to more pollution-tolerant species
- Leaching of toxic chemicals such as phenols, methylated phenols, benzoic acid, benzyl alcohol, terpenes, and tropolones
- Physical alteration of the benthic substrate

The severity of wood waste toxicity depends on the physical form (size), degree of water flushing, and type of wood it is generated from.

COPCs associated with wood waste include resin acids, guaiacols, ammonia, and hydrogen sulfide. Resin acids and guaiacols are naturally occurring organic chemicals found in wood, hardwood tar, and pulp and paper mill processes. Guaiacols also may be derived from creosote and are present in wood smoke, resulting from the chemical decomposition of lignin. The following sections describe the type of processes that produce each of the COPCs listed above.

2.2.1 Conventional Analytes

Ammonia occurs naturally throughout the environment in air, soil, water, and in plants and animals. It is an important source of nitrogen required by plants and animals to live. The largest and most significant use of ammonia and ammonia compounds is the agricultural application of fertilizers. The small portion of commercially produced ammonia not incorporated into fertilizers is used as a corrosion inhibitor, in the purification of water supplies, as a component of household cleaners, and as a refrigerant. It is also used in the pulp and paper, metallurgy, rubber, food and beverage, textile, and leather industries (ATSDR 2004a). Ammonia is produced as a result of anaerobic biodegradation of organic matter, including wood waste.

Hydrogen sulfide is a poisonous, flammable, colorless gas with a characteristic odor of rotten eggs. It occurs both naturally and from man-made processes. Hydrogen sulfide is a component of gases associated with volcanoes, sulfur springs, swamps, stagnant bodies of water, and in crude oil and natural gas. It is also associated with municipal sewers and WWTPs, manure-handling operations, and pulp and paper operations. Hydrogen sulfide is released primarily as a gas and disperses in the air; however, in some instances, it may be released in the liquid waste of an industrial facility or as the result of a natural event. It can change into sulfur dioxide and sulfuric acid, and is soluble in water (ATSDR 2006a). When oxygen is depleted in a water body, anaerobic bacteria partially break down sediment components, expelling hydrogen sulfide.

TOC in sediments is critical to the partitioning and bioavailability of sediment-associated contaminants. Naturally-occurring organic carbon forms are derived from decomposition of plants and animals, but also may be introduced as a result of contamination through anthropogenic activities such as chemical spills (this component typically is relatively small compared to naturally occurring levels, unless a fresh spill has occurred, pure product is present, or a hot spot is sampled). At wood processing locations, the total carbon content contribution of wood wastes may be a significant to dominant fraction of the TOC measured (Schumacher 2002).

TVS represent the fraction of total solids lost on ignition at a higher temperature than that used to determine total solids content and is used to estimate the amount of organic matter present. TVS does not always represent the true organic content of a sample because some organic material may be lost at the drying temperature and some inorganic material (e.g., carbonates and chlorides) may be lost at the ignition temperature. TVS is used to estimate wood content according to DMMP requirements.

2.2.2 Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans

Dioxins and furans are byproducts produced from the combustion of organic compounds with chlorine present and from pulp bleaching processes. Combustion sources include (USEPA 2006):

- Incineration of municipal and medical wastes
- Boilers and industrial furnaces
- Diesel heavy-duty trucks
- Sintering plants
- Automobiles using leaded gasoline
- Oil-fired utilities
- Aggregate kilns that combust hazardous waste
- Petroleum refining
- Crematoriums
- Drum reclamation

Dioxin source assessments conducted in Washington indicate that incinerators, hog fuel (wood waste) boilers, bleached pulp and paper mills, cement kilns, kraft black liquor boilers, tire combustion, and sewage sludge incineration are other potential sources of dioxin production (Ecology 1998). Burning salt-laden hog fuel (wood waste from logs rafted on saltwater) has been implicated in the production of dioxins (Ecology 1998). Because PCP is typically contaminated with low concentrations of dioxins, PCP wood treatment facilities are also a concern (Ecology 1998).

Potential sources of dioxins and furans include historic pulp mill chlorine bleaching operations and the Simpson power plant and historical wood-fired power plants that operated along the south shore of the harbor (former Rayonier pulp and paper mill, former Rayonier burn plant above the pulp mill, and former Simpson/Olympic Plywood plant).

2.2.3 Polychlorinated Biphenyls

PCBs belong to a broad family of man-made organic chemicals known as chlorinated hydrocarbons. PCBs were domestically manufactured from 1929 until they were banned in 1979. They have a range of toxicity and vary in consistency from thin, light-colored liquids to yellow or black waxy solids. Due to their non-flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications including:

- Transformers and capacitors
- Electrical equipment such as voltage regulators, switches, reclosers, bushings, and electromagnets
- Oil used in motors and hydraulic systems
- Old electrical devices or appliances containing capacitors
- Fluorescent light ballasts
- Cable insulation
- Thermal insulation material including fiberglass, felt, foam, and cork
- Adhesives and tapes
- Oil-based paint
- Caulking
- Plastics
- Carbonless copy paper

PCBs have been demonstrated to cause cancer, and a variety of other adverse health effects on the immune system, reproductive system, nervous system, and endocrine system (ATSDR 2001c).

Potential sources of PCBs include transformers located across the Simpson waterfront site.

2.2.4 Chlorinated Pesticides

Organochlorine insecticides were commonly used in the past, but many have been removed from the market due to their health and environmental effects and their persistence.

Dichloro-diphenyl-trichloroethane (DDT) is an organochlorine insecticide once widely used in the U.S. before being banned in 1972. Dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD) are breakdown byproducts of DDT that contaminate commercial DDT preparations. All three compounds are highly persistent and have similar chemical and physical properties; these compounds together are known as total DDT. DDT, DDE and DDD magnify through the food chain, with apex predators (such as raptors) having a higher concentration of these chemicals stored mainly in body fat than in other animals that share the same environment. DDT is also highly toxic to aquatic species, including sea shrimp, crustaceans, and many species of fish. In addition to acute toxic effects, DDT may bioaccumulate significantly in fish and aquatic species, leading to long-term exposure to high concentrations (ATSDR 2002).

Dieldrin and **Aldrin** were developed to replace DDT as insecticides; Dieldrin kills insects directly and Aldrin metabolizes to form Dieldrin within the insect. Dieldrin is persistent and biomagnifies in the environment.

Lindane was used in agriculture as a spray for foliage, to treat soil and seed grains, and in baits for rodent pests. It can kill a broad range of insects including worms that eat leaves, insects that live in the soil, and human and animal parasites such as fleas, ticks and lice. Lindane is a neurotoxin that affects the nervous system, liver, and kidneys and is persistent in the environment.

Heptachlor was widely used for home, lawn and garden pest control, and to control termites and as an insecticide in seed grains and on food crops. It is a persistent organic pollutant.

No specific sources of chlorinated pesticides were found in the historical review of the Oakland Bay study area (Herrera 2008a).

2.2.5 Semi-volatile Organic Compounds

SVOCs are a class of compounds that include PAHs, phenols, PCP, creosols, and phthalates.

PAHs are a group of over 100 chemicals that primarily form by incomplete combustion of carbon-containing fuels, including wood, coal, and gas, garbage, and other organic substances. PAHs are usually found as a mixture consisting of two or more chemicals. They are found in coal tar, crude oil, creosote, roofing tar, and products used to make dyes, plastics, and pesticides (ATSDR 1995c).

Phenols are a class of widely distributed chemicals that are both manufactured and occur naturally. Phenols are used primarily in the production of phenolic resins, the manufacture of synthetic fibers, disinfectants, antiseptic products, algacides, and fungicides (ATSDR 2006b). PCP is a manufactured phenolic chemical that does not occur naturally. It has been widely used as a pesticide and wood preservative and is still used industrially as a wood preservative for utility poles, railroad ties, and wharf pilings (ATSDR 2001b). Creosols are methylphenols and are one of the chemicals that, along with PAHs, are in creosote, which is created from the high temperature treatment of wood, coal, or from the resin of the creosote bush. Creosote has been used as a wood preservative in marine lumber applications (e.g., dolphins, pilings) for over 100 years. Creosote-treated pilings and remnants have been identified as a continuous source of marine pollution, as they leach creosols and PAHs to marine waters and sediments (MRC 2008).

Phthalates are widely-distributed synthetic compounds, primarily used as a plasticizer in the production of flexible polyvinyl chloride products, in ethyl cellulose and nitrocellulose lacquers, resin solvent, paper coatings, adhesives, as a solvent and fixative in perfumes, and in insecticides (ATSDR 2001a).

Potential sources of SVOCs in Oakland Bay include PAHs, phenols, and phthalates associated with plywood and laminate production, produced from machinery and trucks associated with

lumber storage, released during spills/leaks of petroleum-based substances such as hydraulic fluid and fuel, and released from the ITT Rayonier Research Laboratory. SVOCs also are of concern in stormwater and are associated with creosote used to preserve pilings and other wood structures throughout the project site. PCP associated with wood preservation was reportedly used in a dip tank (unknown location) on the Simpson waterfront site. Benzoic acid and phenol are commonly associated with wood waste degradation.

2.2.6 Tributyltins

TBTs are highly toxic compounds used as an anti-fouling agent in marine paints applied to the bottom of boats and can be released to marine sediments during the practice of scraping vessel hulls. NOAA's Mussel Watch Program, studying long-term status and trends, monitors contaminants in sediments and mussels and includes TBTs as an important monitored contaminant (NOAA 2007). Boat maintenance activities at the marine railway area are a potential source of TBTs.

2.2.7 Metals

Metals, such as inorganic arsenic, cadmium, chromium, copper, lead, mercury and zinc occur naturally from geologic processes, and are also used extensively in manmade products. Common sources of these metals from processes include:

- **Aluminum** – the most abundant metal in the earth's crust, is used for beverage cans, pots and pans, airplanes, siding and roofing, and foil. Aluminum is often mixed with small amounts of other metals to form aluminum alloys, which are stronger and harder (ATSDR 2010).
- **Antimony** – the most widely used antimony compound is antimony trioxide, used as a flame retardant. It is also found in batteries, pigments, and ceramics/glass (USEPA 2010a).
- **Arsenic** – wood preservative (chromated copper arsenate or CCA) in utility poles, building lumber, and pilings; and in herbicides and pesticides (ATSDR 2007a; Lewis 1997)
- **Barium** – used in making a wide variety of electronic components, in metal alloys, bleaches, dyes, fireworks, ceramics and glass. It is used in some well drilling operations where it is directly released into the ground (USEPA 2010b).
- **Cadmium** – nickel-cadmium batteries; pigments used in plastics, ceramics, and glasses; stabilizers for PVC; coatings on steel and some nonferrous metals; components in various specialized alloys; and in fungicides (ATSDR 1999a; Lewis 1997)

- **Chromium** – alloying and plating element on metal and plastic substrates for corrosion resistance, including high temperature industrial furnaces and cooling towers, pigments, and in wood preservatives (ATSDR 2000; Lewis 1997)
- **Copper** – electroplated protective coatings; anti-fouling paints; car brake dust; incineration; chemical and pharmaceutical machinery; corrosive-resistant piping; insecticides; and electrical wiring, plumbing, heating, roofing, and building construction materials (ATSDR 2004b; Lewis 1997)
- **Lead** – batteries; gasoline; lead alloys used in bearings, brass and bronze, and some solders; radiation shielding; cable covering; chemical resistant linings; ammunition; and pigments in glass making, ceramic glazes, plastic stabilizers, caulk, and paints (ATSDR 2007b; Lewis 1997)
- **Mercury** – cathodes for production of chlorine and caustic soda; catalysts for manufacture of certain polyurethanes; electrical apparatus; instruments (thermometers, barometers, etc.); amalgam; light fixtures; mirror coating; boilers; and fungicide in paint (banned since 1990) (ATSDR 1999b; Lewis 1997)
- **Nickel** – alloys, electroplating, batteries, coins, industrial plumbing, spark plugs, machinery parts, stainless-steel, nickel-chrome resistance wires, and catalysts (USEPA 2010c).
- **Zinc** – alloys; galvanizing iron and other metals; white pigment; fertilizers and animal feed as trace element and disease-control agent; manufacture of rayon (as a crendulating agent), in paper bleaching, and glue; wood preservative; catalyst; waterproofing agent; and in fungicides (ATSDR 2005; Lewis 1997).

Potential sources of heavy metals in Oakland Bay include non-contact cooling water, stormwater, and discharges from the former ITT Rayonier Research Laboratory.

2.2.8 Petroleum Hydrocarbons

Petroleum products such as gasoline, fuel oil (including diesel fuel), and mineral-based crankcase motor oil are distilled from crude oil and are refined to meet specifications for each use.

Gasoline is a mixture of over 150 compounds, including benzene, toluene, ethylbenzene, and xylenes. Organic lead compounds were added to gasoline as anti-knock agents before the mid-1980s. Gasoline is used exclusively for internal combustion engines in automobiles and other vehicles (ATSDR 1995b).

Fuel oils are mixtures of aliphatic and aromatic petroleum hydrocarbons, and may also contain small amounts of nitrogen, sulfur, and other elements as additives. Six types of fuel oil include:

- Fuel oil No. 1 – kerosene, range oil, coal oil, and jet fuel
- Fuel oil No. 1-D – diesel fuel
- Fuel oil No. 2 – home heating oil, No. 2 burner oil, and gas oil
- Fuel oil No. 2-D – No. 2 diesel
- Fuel oil No. 4 – heavy residual fuel oil, marine diesel fuel, and diesel fuel oil No. 4
- Fuel oil Nos. 5 and 6 – Bunker C fuel oil

Fuel oils have many commercial and military uses, including jet fuel, home heating oil, fuel for trucks and heavy machinery, as a carrier for insecticides and fungicides, road oil; and gas compression (ATSDR 1995a).

Mineral-based crankcase motor oil consists of aliphatic and aromatic hydrocarbons, or PAHs, that are distilled from crude oil. Various additives may be included in motor oil to improve performance. Metals such as aluminum, chromium, copper, iron, lead, manganese, nickel, silicon, and tin, are found in used motor oil derived from engine parts as they wear down. Motor oil is used as fuel in boat engines, furnaces and oil burners for domestic and industrial power plants, industrial steam boilers, municipal incinerators, and rotary cement kilns (ATSDR 1997).

Potential sources of petroleum hydrocarbons include significant releases associated with product storage facilities.

3.0 Field Investigation Methods

The Oakland Bay study included a geomorphic assessment to evaluate physical processes driving the accumulation and movement of sediment across the bay, and collection of sediment samples for chemical and biological testing to determine the distribution of chemicals and the potential for toxicity. Field investigations included a geophysical study and collection of both surface and subsurface sediment samples. All field work was conducted on boats equipped with specialized equipment to complete each task.

3.1 Geomorphic Assessment

Geomorphic assessment of the study area was based on the following sources of data:

- A general review of geological processes leading to the physical structure of the near-surface environment
- Geophysical surveys using several acoustic and resistivity methods
- Sediment core logging to determine lithology across the bay
- Radioisotope dating of core samples to evaluate sedimentation rates

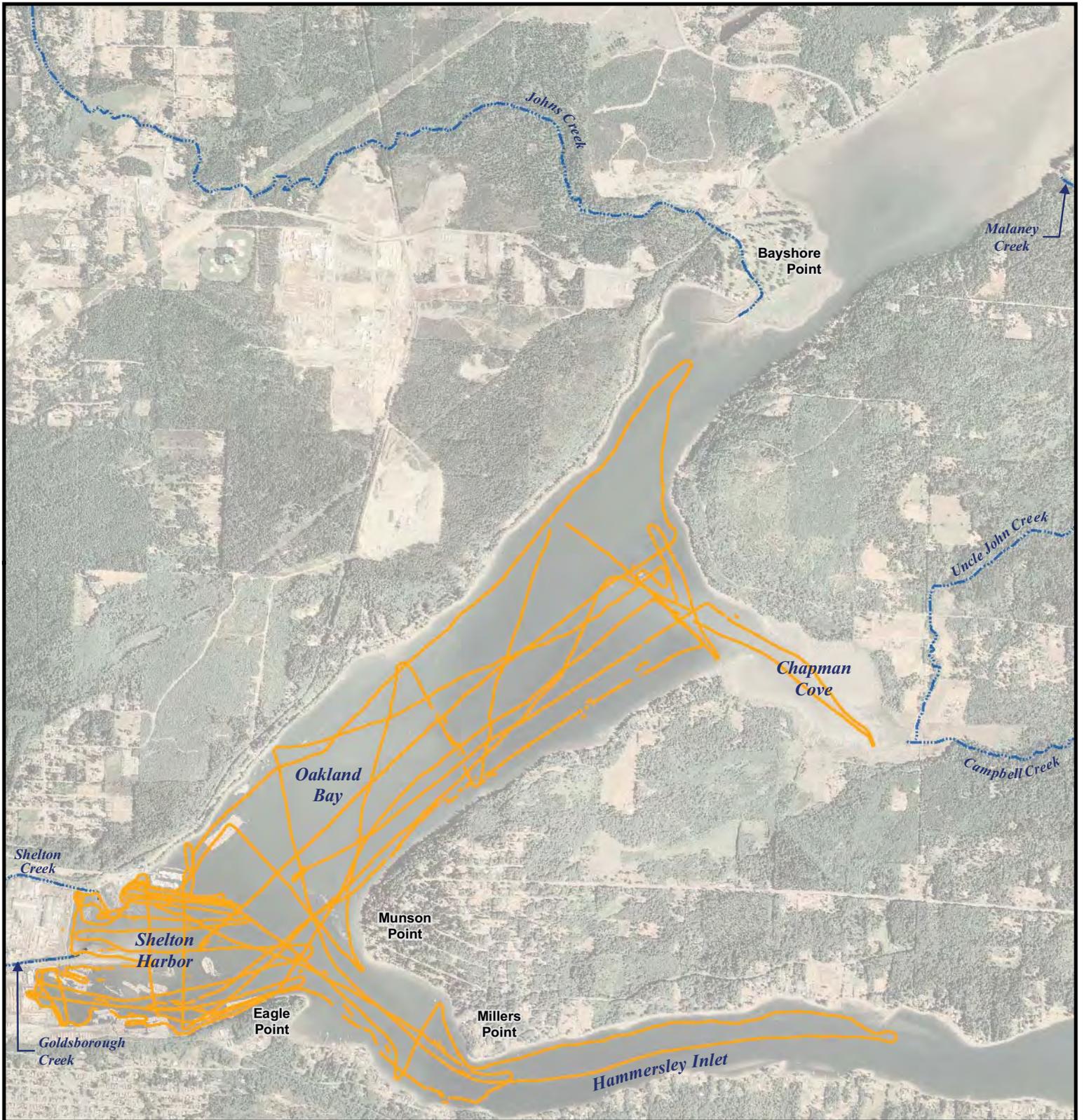
Field investigation involved a visual inspection of the site and surrounding area, conducting a series of geophysical surveys using equipment mounted on a boat, and collecting sediment surface grab and core samples from boats. Five different geophysical data collection methods and two types of sedimentation assessments were conducted to meet the study objectives. Sedimentation assessments were performed on sediment cores, based on both visual interpretation of lithology and laboratory radioisotope analyses of cesium-137 and lead-210.

3.1.1 Geophysical Study

Surface geophysical assessments included three acoustic methods (sonar, acoustic tomography, and side-scan sonar), electrical resistivity, and induced polarization. Survey results were used to determine changing sediment characteristics, including potential accumulations of wood waste, to help position sediment samples collected at a later date. The survey was conducted across Hammersley Inlet, Shelton Harbor, and Oakland Bay; however, much of Shelton Harbor and the head of the bay were inaccessible due to shallow conditions. The geophysical survey transects are shown on Figure 3-1; a detailed description of activities is provided in Appendix E.

3.1.1.1 Bathymetric Sonar

Sonar was used to develop a sediment surface map, identifying key geomorphic bottom features such as ripples and dunes. Bathymetric data were acquired using an echosounder with a

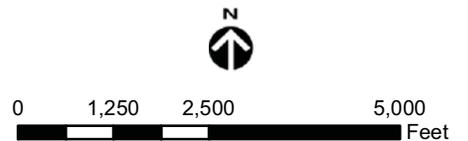


Legend

— Geophysical survey transect

Figure 3-1.

Geophysical survey transect lines across the Oakland Bay study area.



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300 kilohertz (kHz) transducer mounted to the side of the research vessel. The echosounder works by emitting a focused beam of sound directly downward. The return time of sound from the bed (the peak reflector) is recorded with time. Data were collected as the vessel traveled across the entire study area and were then matched with global positioning system (GPS) measurements that were time-stamped and acquired separately. Once the speed of sound is estimated, the distance from the water surface to the bed can be calculated. These measurements can then be referenced to a tidal datum (mean lower low water [MLLW]) using tide observations made in Tacoma.

3.1.1.2 *Acoustic Tomography*

Shallow acoustic tomography (imaging) of the seabed was used to image the top several feet of the seabed to determine important geological intervals that could be related to wood waste presence, both past and present. It differs from sonar (bathymetric and side-scan) because the sound waves penetrate the seabed and provide information about the internal structure of the seabed.

Shallow acoustic tomography works by emitting a low frequency (4 to 24 kHz) sound wave from an acoustic transducer towed behind the research vessel. Data were collected continuously as the vessel traveled across the study area. Subsurface reflection data (i.e., the returning sound and its record in time) were acquired with the same transducer. These data were correlated in space with GPS, providing a “trace” of reflections in the seabed, creating a two-dimensional map of reflective surfaces. Differences in sediment composition produce variously reflective surfaces; the presence of woody material may be discernable based on its physical properties, such as increased porosity relative to the surrounding sediment. The reflectivity map can provide information about sedimentation rates and sediment transport directions when combined with other geomorphic information.

In any acoustic sub-bottom survey, a balance must be struck between signal penetration and resolution, which is controlled by changing the frequency of the sound used. A low frequency source can penetrate deep into the seabed, but lower frequencies do not result in better resolution of features provided by higher frequency waves. In this study, the layer of interest typically was only 1 to 2 feet (0.3 to 0.6 meters) thick, supporting the use of a high frequency sound source (a low sampling frequency would not resolve the thin, wood-containing deposit covering much of the bay). A broadband source was used to maximize both resolution and penetration.

3.1.1.3 *Side-Scan Sonar*

Side-scan sonar was used to identify shapes on the seabed, including large woody debris and other acoustically reflective disposed items or materials. A digital image of the seabed was created using side-scan sonar (300 kHz) instrumentation. Side-scan sonar broadcasts sound throughout a wide swath along the seabed from a towed source, receiving sound back at the same transducer. By converting the travel times of sound returning to the probe into distance, a “picture” of the reflectivity of the seabed can be created. Because it uses a different frequency

than the other tools, it can be performed simultaneously with other data collection activities (i.e., bathymetric sonar and acoustic tomography).

3.1.1.4 *Electrical Resistivity*

Electrical resistivity imaging detects differences in electrical properties of geologic materials. Identifying geologic differences can provide evidence of changes in sedimentation patterns with time and, in some cases, identify different types of contamination (e.g., the presence of wood waste). Differences in electrical resistivity properties can result from variations in lithology and mineralogy, water content, or pore-water chemistry. Organic material, such as wood waste, generally is more resistive than the inorganic sediment; therefore, electrical resistivity can help identify wood-containing layers in the seabed.

Electrical resistivity works by laying a cable that has a series of electrodes (exposed wire separated by insulated cable) along its length. Alternating electrodes induce a current in the seabed. An adjacent pair of electrodes measures the voltage associated with the imposed current. By analyzing the pattern of voltages that result, a two-dimensional resistivity map of the shallow subsurface can be made. An electrode spacing of 1 foot (0.3 meter) was used to resolve the thin layers of wood waste present in the harbor.

Electrical resistivity did not provide useful data for this study (discussed in Section 4.1.1.4).

3.1.1.5 *Induced Polarization*

Induced polarization involves transmitting an electric current into the ground between two electrodes and measuring the voltage response between two separate potential electrodes after the current is stopped. Like traditional electrical resistivity, induced polarization detects differences in resistivity and can produce a two-dimensional map of electrical properties along a length of cable, which can be used to estimate wood waste volumes and extent. Unlike electrical resistivity, induced polarization emphasizes boundaries of like material, rather than the overall electrical character of the seabed. Therefore, induced polarization can detect changes in sedimentation patterns in the seabed and identify patches of different types of contamination (e.g., the presence of wood waste).

Induced polarization did not provide useful data for this study (discussed in Section 4.1.1.5).

3.1.2 *Sediment Core Sampling*

Sediment cores collected for chemical analysis also were evaluated for lithology. Cores were processed onsite and logged by a licensed geologist based on:

- Physical soil description in accordance with the Unified Soil Classification System (USCS)
- Color

- Odor
- Visual stratifications and lenses
- Vegetation
- Wood content by percent
- Biological activity (e.g., detritus, shells, tubes, bioturbation, live or dead organisms)
- Presence of oil sheen or obvious contamination
- Other distinguishing characteristics or features

The detailed sampling procedure is discussed in Section 3.6.2.

3.1.3 Radioisotope Core Sampling

Sediment core samples were collected as described in Section 3.6.2 and submitted to the laboratory for lead-210 and cesium-137 analyses. Radioisotopes distributed vertically in the sediment provide a record of recent sedimentation based on the rate at which cosmogenic (i.e., derived from radiation from outer space) isotopes decay. Cores were divided into 0.8-inch (2 cm) sections and the loss of radioactivity determined with depth (only select core sections were analyzed). Cesium-137 entered the environment starting in approximately 1946, as a result of thermonuclear activities, so its presence provides a timeframe benchmark. Lead-210 radioactivity is lost as sediment becomes buried and protected from cosmogenic radiation by the sediment accumulating above. The rate at which the activity is lost vertically in the core directly correlates to the sedimentation rate. This information, combined with sediment core logs and geophysical survey results, allows estimation of sedimentation rates at the each sampled location. The pattern of sedimentation rates across the bay, determined by comparing multiple sample locations, helps to elucidate the direction of sediment transport.

3.2 Sample Types

Fifty surface grab and 48 subsurface core samples were collected across the study area for chemical analysis, and three core samples were obtained for radiological analysis (Figures 3-2 and 3-3); additionally, three reference sediment surface grab samples were collected from Carr Inlet. Samples were analyzed to evaluate the potential presence of chemicals associated with industrial activities and chemicals associated with decaying wood, and to evaluate the deposition rate of sediment across the study area. As such, sampling locations were designated based on the targeted “matrix” of concern (see Section 3.3), including standard sediment, sediment likely to contain significant wood waste, and sediment to be collected for radioisotope analyses.

Surface samples were collected using a Van Veen grab sampler, retrieving approximately 4 inches (10 cm) of sediment. Subsurface samples were collected using a vibrating core device retrieving 4 to 12 feet (1.2 to 3.7 meters) of sediment. Most subsurface cores penetrated to a depth of 6 feet (1.8 meters). If wood waste was visually present at the bottom of the core, a second core was obtained adjacent to the first, extending up to 12 feet deep for further visual analysis.

Surface grab samples were collected at every sampling location, except radioisotope core locations. They were visually inspected for wood content, analyzed for chemical constituents, and analyzed for biological toxicity (bioassay). Samples collected at designated wood waste locations were analyzed for wood waste constituents in addition to industrial COCPs. All surface grab samples were analyzed for dioxins and furans. Selected stations were also analyzed for TBTs and petroleum hydrocarbons.

Subsurface core samples were collected at every sampling location, separated into 1 foot (0.3 meter) lengths, and visually inspected for wood content. Core sections from the 1-2 foot depth interval for all stations in Shelton Harbor and at the three wood waste locations in Oakland Bay were analyzed for industrial COCPs (no dioxins/furans). Samples collected at designated wood waste locations were analyzed for wood waste constituents in addition to industrial COCPs. Selected stations were analyzed for TBTs and petroleum hydrocarbons. All other 1 foot (0.3 meter) core sections were frozen and archived for possible future analysis. Selected 1-2 foot and 2-3 foot archived core sections were later analyzed for dioxins/furans based on surface analytical results.

Three designated cores were analyzed for radioisotope constituents; every third 0.8 inch (2 cm) core section was initially analyzed for lead-210 and the remainder archived for future cesium-137 analysis, which was performed on two cores.

3.3 Sample Designation

Samples were identified based on the sampling area, location, and sample depth. Each sample was labeled with a unique alphanumeric sample identification number that identifies characteristics of the sample, as follows:

Study Location

SH – Shelton Harbor

OB – Oakland Bay

HI – Hammersley Inlet

RF – Reference

Station Location (associated with each Study Location)

01 – Sample Station 1

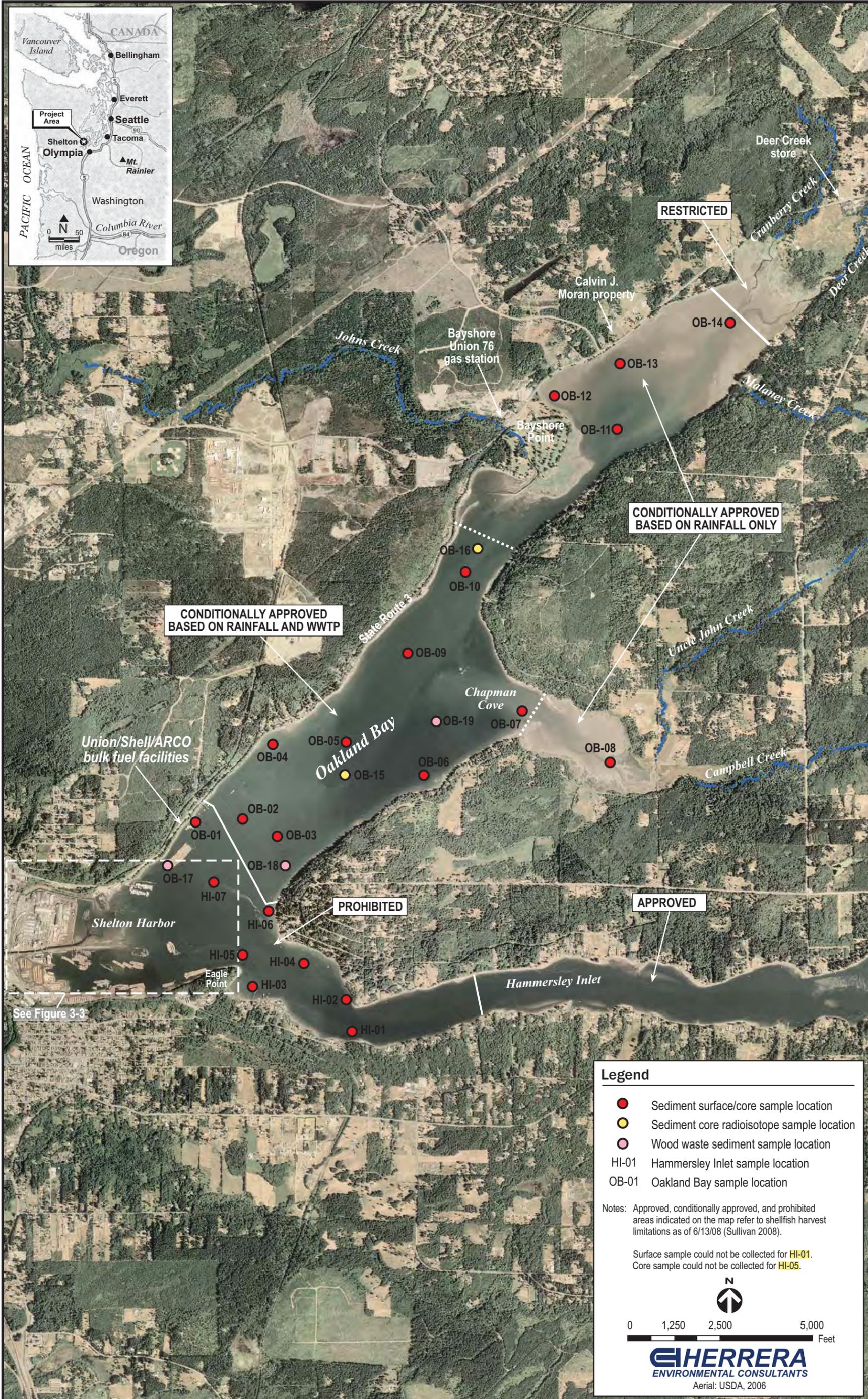


Figure 3-2. Sediment and wood waste sample locations in Oakland Bay and Hammersley Inlet.



Figure 3-3. Sediment and wood waste sample locations in Shelton Harbor, Shelton, Washington.

Matrix

SS – Sediment Surface
SC – Sediment Core
RI – Radioisotope
WS – Wood Waste Surface Sediment
WC – Wood Waste Core Sediment

Depth

00 – Surface
01 – 0 to 1 foot
12 – 1 to 2 feet
23 – 2 to 3 feet
34 – 3 to 4 feet
04 – 0 to 4 feet (radioisotope only)

For example:

- SH-01-RI-04 = Shelton Harbor, Station 1, Radioisotope, 0-4 foot interval
- OB-09-SC-12 = Oakland Bay, Station 9, Sediment Core, 1-2 foot interval

3.4 Field Investigation Schedule

The Oakland Bay sediment investigation was conducted in two phases: a geophysical survey conducted between June 25 and 27, 2008, and sediment sampling conducted between September 29 and October 20, 2008.

Geophysical data collection was conducted on a boat equipped with GPS and geophysical instruments. Multiple survey crossings were conducted to accommodate each measurement technique (Figure 3-1).

Sediment sampling was conducted on two sampling vessels simultaneously, with one team collecting surface grab samples and another team collecting subsurface core samples. Both boats were equipped with GPS and appropriate equipment for deploying samples and decontaminating of equipment.

Reference sediment sampling was conducted at Carr Inlet on October 9, 2008.

3.5 Station Positioning and Navigation

3.5.1 Geophysical Survey

The position of the vessel was determined using a Trimble Ag132 DGPS, with differential correctors obtained from the U.S. Coast Guard beacon. The navigation computer was interfaced with the geophysical instrumentation used for data gathering.

3.5.2 Sediment Sampling

The position of sampling vessels was determined using a Trimble Ag132 DGPS, with differential correctors obtained from the U.S. Coast Guard beacon. The differential global positioning system (DGPS) receiver was capable of surveying positions to within 6 foot (2 meter) accuracy. Horizontal coordinates were referenced to the Washington State Plane coordinate system under the North American Datum of 1983 (NAD 83).

Coordinates of the proposed sampling stations were programmed as waypoints into the vessel's navigation system and used to guide the vessel to the appropriate locations. The DGPS receiver was placed above the sampling device deployment boom to accurately record the position. At both surface sediment grab and subsurface core stations, once the sampling device was deployed, the actual position was recorded when the device reached the sediment floor and the deployment cable was in a vertical position. At these locations, water depths were measured directly by lead-line and converted to mudline elevations after correction for tide.

An attempt was made to locate sample stations as established in the *Sampling and Analysis Plan*, which included 56 stations. Neither surface or core samples could be collected at one location (SH-06), surface grab samples could not be collected at two locations (HI-01 and SH-08), and core samples could not be collected at four locations (HI-05, SH-03, SH-24, and SH-25), primarily due to the presence of cobbles, large wood interference, or otherwise hard surfaces. The coordinates associated with final sampling stations are provided in Appendix A and positions are shown on Figures 3-2 and 3-3.

3.6 Sample Collection and Processing Methods

3.6.1 Surface Grab Samples

Surface sediment and wood waste samples were collected from a boat using a stainless-steel Van Veen grab sampler. Up to three grab attempts were made at each proposed sampling location, depending on the amount of sample recovered. When unsuccessful, the station was moved to a new location, typically within 30 feet (10 meters) of the original station. Three sample stations (SH-06, SH-08, HI-01) could not be sampled despite moving to new locations.

Surface sediment and wood waste samples were collected from the 0 to 4 inch (0 to 10 cm) interval. Multiple grabs were typically necessary to obtain an adequate sample volume for all analyses. Samples were carefully collected to ensure the following conditions were met, as required by Ecology (2008):

1. Logbook and field form entries were made as necessary throughout the sampling process to ensure accurate and thorough record-keeping.
2. The sampling vessel was positioned at the targeted sampling stations using a DGPS.

3. The sampler jaws were set in the open position, the sampler was placed over the edge of the boat, and lowered to the bottom.
4. The sampler was tripped to collect the sample.
5. The station position was recorded based on DGPS coordinates.
6. The sampler was retrieved and placed in the sampling vessel.
7. The sample was examined for the following acceptance criteria:
 - The sampler was not overfilled with sample so that the sediment surface was not pressed against the top of the sampler.
 - The sample did not contain large foreign objects (i.e., trash or debris); a sample that was primarily wood, rock/gravel fill, or shells was rejected in favor of depositional material (i.e., sand/silt/clay).
 - Overlying water was present in the sampler, indicating minimal leakage.
 - The overlying water was not excessively turbid indicating minimal sample disturbance.
 - The sediment surface was relatively flat, indicating minimum of disturbance or winnowing.
 - The desired penetration depth was achieved (e.g., several inches more than the targeted sample depth).
8. If sample acceptance criteria were not achieved, the sample was rejected and another sample collection attempt was made.
9. Overlying surface water was siphoned off.
10. Samples for total sulfides and Microtox analysis were collected directly from the grab sampler and sediment aliquots were placed in appropriate, pre-cleaned, labeled sample containers. Containers were filled to the brim to minimize headspace.
11. The top 4 inches (10 cm) was removed with a stainless steel spoon, avoiding any sediment in contact with the inside surface of the grab sampler, and placed into a stainless steel bowl, homogenized, and covered with aluminum foil.

12. The following observations of sediment sample characteristics were recorded in the field logbook (when more sample volume was required, steps 4 through 11 were repeated) Field observations are found in Appendix D:
 - Texture
 - Color
 - Biological organisms or structures (i.e., shells)
 - Presence of debris (i.e., natural or anthropogenic objects, including wood and its general size, – identifying bark, wood chips, fibers, and sawdust relative abundance by percent)
 - Presence of oily sheen or obvious contamination
 - Odor (e.g., hydrogen sulfide, petroleum)
13. Excess sediment was washed back into the water away from any areas remaining to be sampled.
14. Once sufficient sediment volume was collected, samples were placed in the appropriate, pre-cleaned, labeled sample containers, placed in a cooler maintained at 4°C, and prepared for shipment to the analytical laboratory.
15. All relevant documentation was checked for completion and accuracy, and then was signed.
16. All sampling equipment was decontaminated before proceeding to the next sampling location.

Additional sample volume was collected at stations requiring matrix spike/matrix spike duplicate (MS/MSD) analysis (collected randomly at the field supervisor's discretion).

An aliquot of each homogenized sample was wet sieved in the field to determine the relative amount of coarse and fine-grained material to match appropriate test and reference samples for toxicological (bioassay) testing. The procedure for wet sieving was as follows:

1. A 3.3 oz (100 milliliter) beaker was completely filled with an aliquot of homogenized sediment; the beaker was tapped to remove air bubbles and to level the surface.
2. The entire contents of the beaker were rinsed through a 0.00248 inch (63 micron; #230, 4 phi) sieve until clear rinse water passed through the sieve.

3. The coarse-grained material was transferred from the sieve into an 8.5 oz (250 milliliter) graduated cylinder.
4. The amount of material measured in the bottom of the graduated cylinder was divided by the capacity of the beaker to determine the decimal percentage of coarse-grained material. The decimal percentage of coarse-grained material was subtracted from 1 to determine the decimal percentage of fines (silt and clay).
5. The percentage of coarse and fine-grained material was recorded in the field logbook.

3.6.2 Subsurface Core Samples

Core samples were collected using a vibracoring device. In most cases, the cores were advanced 7 feet (2.1 meters) to ensure adequate sediment retrieval (actual depth depended on sediment characteristics). Each core was divided into 1 foot (0.3 meter) intervals, which were placed into sample containers either for analysis or archiving.

The general procedure for collecting sediment cores was as follows:

1. Logbook and field form entries were made throughout the sampling process to ensure accurate and thorough record-keeping.
2. The sampling vessel was positioned at the targeted sampling stations using DGPS.
3. Pre-cleaned acetate core tubes were inserted into the aluminum core tubes equipped with an “eggshell” core catcher to retain material in the core barrel for deployment.
4. The core-sampler was positioned vertically on the bottom and advanced to a sampling depth of between 4 feet (1.2 meter) to 12 feet (3.7 meter) to include all targeted sampling intervals or until refusal.
5. Once sampling was complete, the sampler was extracted and the core tube detached from the vibracorer. The core sample was examined at each end to verify that sufficient sediment was retained. The condition and quantity of material within the core was then inspected to determine acceptability. If sample acceptance criteria were not achieved, the sample was rejected and another sample collection attempt made.
 - To verify whether an acceptable core sample was collected, the following criteria were evaluated:
 - Target penetration depth or refusal was achieved

- Sediment recovery of at least 65 percent of the penetration depth
 - Sample appeared undisturbed and intact, without any evidence of obstruction or blocking within the core tube or core catcher.
- Percent sediment recovery was determined by dividing the length of material recovered in the core tube by the depth of core penetration below the mudline. If the sample was deemed acceptable, overlying water was siphoned from the top of the core tube, and each end of the tube capped and sealed with duct tape for storage until processing. The cores were generally processed within 1 to 3 hours following collection; if processing was delayed, they were stored on ice. The station number, station coordinates, date and time of collection, sediment description, field crew, and weather conditions were recorded in the sediment coring log.
6. Observations of sediment sample characteristics were recorded on the core logs.
 7. If significant wood content was noted at the bottom of the core (identified at three locations), another deeper core sample was collected at the same station.
 8. All relevant documentation was checked for completion and accuracy, and then was signed.
 9. All sampling equipment was decontaminated before proceeding to the next sampling location. Used core tubes were rinsed and then placed in the marina dumpster. Excess sediment generated during core processing was returned to the bay.

Disposable nitrile gloves were worn for all handwork such as sectioning the core, sub-sampling, mixing samples, and filling sample containers. The gloves were disposed of between samples to prevent cross contamination. Sampling implements and processing equipment were decontaminated before processing each sediment core. Each core tube was cut open length-wise using a box cutter. Care was taken to preserve integrity of the core section strata. A visual characterization of the sample material was conducted for each foot (0.3 meter) of the core while processing. The core logs are included in Appendix B.

Representative aliquots were collected from each 1 foot (0.3 meter) interval using a decontaminated stainless steel spoon. Sediment was collected from the center of the core not smeared by, or in contact with, the core tube surface. Sediment from each 1-foot (0.3-meter) section was placed in a decontaminated stainless steel bowl and mixed until homogenous in texture and color.

Sample aliquots for sulfide were separated from the 1-2 foot core section before sample homogenization (to minimize losses associated with volatilization) and placed in appropriate, pre-cleaned, labeled sample containers. Containers were filled to the brim to minimize headspace. The remaining sample was homogenized and sample aliquots for grain size and TOC placed into containers. The remaining 1-2 foot core material was placed into the applicable sample containers for immediate analysis or stored to be frozen for potential future analysis. Each of the remaining 1-foot (0.3-meter) core increments were separately homogenized and placed in large sample jars for archiving.

The three cores collected for radioisotope analyses were approximately 4 feet (1.2 meter) in length. The cores were divided into 0.8 inch (2 cm) intervals and containerized in the field; every third interval was analyzed for lead-210 and the others archived. Follow up cesium-137 analysis was conducted on archived core sections selected based on lead-210 results.

3.7 Sample Handling

Surface grab samples were processed on the sampling vessel and brought to the landside core processing area to be packaged for transport. Subsurface core samples were processed shortly after delivery from the sampling vessel. Cores were delivered and stored in a vertical position before processing, and kept on ice if held for longer than 4 hours.

3.7.1 Chain-of-Custody Procedures

At the end of each sampling day, sediment samples were removed from the coolers and checked against the field sample log. Sample collection information was then entered on chain-of-custody (COC) forms. Sediment samples were placed into coolers with fresh ice arranged by analytical laboratory for transport. Custody forms were signed by the sample crew leader and placed into the coolers.

3.7.2 Sample Transport Procedures

All samples were kept under control of field personnel until released to a laboratory courier or FedEx for shipment. Sample coolers were transported to the analytical laboratories using the following methods:

- Laboratory personnel picked up sample coolers from site
- Herrera personnel hand delivered sample coolers to laboratory personnel or to the laboratory
- Herrera personnel shipped sample cooler to the laboratory via FedEx

3.8 Chemical and Physical Analyses

COPCs for the Oakland Bay study were selected based on chemicals commonly associated with industrial activities in the area and byproducts associated with wood waste degradation (Section 2.2). Surface sediment samples were sent to laboratories for chemical or bioassay testing, and subsurface core samples were sent to laboratories for either chemical or radiological testing.

The analytical regime for this study is detailed in Appendix C and summarized below. The rationale for both collection of each sample and the analytical testing conducted at each location is provided in Section 4 of the *Field Sampling and Analysis Plan – Oakland Bay Characterization Study* (Herrera 2008b).

- Surface samples:
 - All surface samples were analyzed for industrial COPCs, including SVOCs, pesticides, dioxins/furans, PCB Aroclors, and heavy metals; select locations were tested for petroleum hydrocarbons.
 - All surface samples at designated wood waste locations were tested for resin acids, guaiacols, and TVS; archived samples from several non-wood waste locations were later analyzed for resin acids based on initial results.
 - All surface samples were tested for grain size distribution, TOC, sulfides, and ammonia.
 - Bioassays were performed on all surface samples to address SMS biological effects criteria; two acute effects tests (amphipod and larval) and two chronic effects tests (juvenile polychaete and Microtox) were conducted.
- Subsurface samples:
 - Initial chemical analyses were performed on some 1-2 foot core sections, and all other 1-2 foot cores and deeper core sections were frozen for potential future analysis.
 - 1-2 foot core sections from all locations within Shelton Harbor and from the three designated wood waste stations within Oakland Bay were analyzed for SVOCs, pesticides, PCB Aroclors, and heavy metals (the same suite as for surface samples, with the exception of dioxins/furans). Select locations were tested for TBTs and petroleum hydrocarbons.

- Selected archived samples from 1-2 feet and/or 2-3 feet were later tested for dioxins/furans, based on initial surface sample results.
- 1-2 foot core sections at all designated wood waste locations were tested for resin acids, guaiacols, and TVS.
- All 1-2 foot core sections were tested for grain size distribution, TOC, sulfides, and ammonia.
- Radiological analyses were performed on sediment cores collected at three locations independent of those collected for chemical and biological analyses; samples at two of the stations were analyzed for lead-210 and cesium-137; the Shelton Harbor station was tested only for lead-210.

3.9 Analytical Methods

The chemical analytical procedures used in this program followed the most recent SMS and PSEP protocols and guidelines, and Ecology's Sediment Sampling and Analysis Plan Appendix (2008). Each laboratory participates in the National Laboratory Accreditation Program and/or has been accredited by Ecology's laboratory certification program (173-50 WAC).

3.9.1 Chemistry

Three analytical laboratories were used to analyze sediment samples for chemical parameters, as described below.

Samples submitted to Analytical Resources, Inc in Tukwila, Washington were analyzed for the following parameters:

- TOC, grain size, ammonia, and total sulfides by PSEP methods
- TVS by USEPA method 160.4
- SMS SVOCs and guaiacols by USEPA method 8270
- Wood resins by USEPA method 8270 modified
- TBTs in bulk sediment by Krone 1989

Samples submitted to Test America in Tacoma, Washington were analyzed for the following parameters:

- Metals by USEPA methods 6020 and 7471 (mercury)
- Organochlorine pesticides by USEPA method 8081
- PCBs by USEPA method 8082
- Petroleum hydrocarbons by Ecology's NWTPH-HCID method

Samples submitted to Axys Analytical Services in Sydney, British Columbia, Canada were analyzed for dioxins/furans using USEPA method 1631.

3.9.2 Bioassay

Samples were submitted to NewFields Northwest in Port Gamble, Washington for bioassay testing. Four different toxicity tests were used to test sediments from Shelton Harbor, Oakland Bay, and Hammersley Inlet. As more than 25 percent of the samples were collected from water depths of less than 12 feet (4 meters) MLLW, all bioassay tests except for the Microtox test were conducted under ultra-violet (UV) light (Ecology 2008).

3.9.2.1 10-Day Amphipod Test

The 10-day amphipod sediment toxicity test using *Ampelisca abdita* and *Eohaustorius estuarius* was conducted on project sediments using the protocol found in the *Recommended Guidelines for conducting laboratory bioassays on Puget Sound Sediments* (PSEP 1995). Two separate batches were run based on grain size of the respective samples. The first batch of 20 samples (greater than 60 percent fines) plus two reference sediment samples used test organism *A. abdita*. The second batch of 30 samples (less than 60 percent fines) plus two reference sediment samples used test organism *E. estuarius*. This is a 10-day acute toxicity test with mortality as the measured endpoint.

3.9.2.2 Larval Development Test

The larval development test used the mussel *Mytilus sp.* as the test organism, in accordance with methods described in PSEP protocols (1995). Tests were split into two batches with 26 and 24 samples, respectively, plus all three reference samples with each batch. This is a 2- to 4-day acute toxicity test, with an endpoint of normal survival.

3.9.2.3 Juvenile Polychaete Growth Test

The polychaete growth test used *Neanthes arenaceodentata*, in accordance with methods described in PSEP protocols (1995). Tests were split into two batches with 25 samples each plus all three reference samples with each batch. The juvenile polychaete growth test is a 20-day chronic test with endpoints of mortality and growth.

3.9.2.4 Microtox Test

This test assesses toxicity in sediment porewater using bioluminescent properties of the marine bacteria *Vibrio fischeri*. The test was conducted in accordance with methods described in the *Sediment Sampling and Analysis Plan Appendix B* (Ecology 2008). Fourteen separate batches were run, each with one to four sediment samples plus the appropriate reference samples. The Microtox test is a rapid (15 minute) exposure of bacteria to sediment porewater with the endpoint measured in luminescence at 5 and 15 minutes.

3.9.3 Radiology

Samples were submitted to Test America in Richland, Washington for radiological analysis of three sediment cores using gamma spectroscopy to estimate historical sediment accumulation.

Laboratory analyses consisted of lead-210 and cesium-137 radioisotope activity measurements. Each sample was analyzed for disintegrations per minute per gram; lead-210 analysis was performed on every third 0.8 inch (2 cm) section of all three cores and cesium-137 analysis was performed on three sections of OB-15 and five sections of OB-16 (cesium-137 test sections were selected based on lead-210 results and core lithology – cesium-137 analysis was not appropriate for the Shelton Harbor core).

4.0 Field Investigation Results

This section presents field investigation results. Interpretations of collected data are provided in later sections (primarily in Chapters 5, 6, and 7).

4.1 Geomorphic Assessment

A geomorphic assessment of the Oakland Bay study area was conducted by:

- Performing a general review of geological processes leading to the physical structure of the near-surface environment
- Performing geophysical surveys using three acoustic methods and two resistivity methods
- Reviewing sediment core logs to determine lithology across the bay
- Radioisotope dating of sediment cores to evaluate sedimentation rates

Investigative work was conducted in the order described above, with preliminary results of the first two efforts used to help position sample stations for location-specific data collection. The overall assessment was then developed based on a combination of all information collected. The first two endeavors addressed more general, area-wide information; the second two endeavors used location-specific information. The data were used to generate a bay-wide model of sediment input and transport, which also included a wood waste component, introduced as a result of wood processing that began in the late 1800s. The sediment transport model is discussed in Appendix E and in Sections 5 and 7 of this report.

Results of the first two steps of the assessment are provided in Appendix E; specific results of each geophysical survey and both of the other steps are presented below.

4.1.1 Geophysical Surveys

The geomorphic assessment was conducted to understand how sediment and wood waste have deposited across the bay and the mechanisms for movement within the bay. The geophysical study was performed to map the seabed and determine the vertical and lateral extent of recent deposition, including the wood waste component.

Shallow or obstructed areas of Shelton Harbor and shallow portions of Oakland Bay in Chapman Cove and north of Bayshore Point were not surveyed because of restricted boat access. Sediment bed characteristics were identified by bathymetric sonar, acoustic tomography, and side-scan sonar. Each of these techniques proved to be effective, relying on acoustic waves reflected off

the seabed. The two electromagnetic methods (electrical resistivity and induced polarization) were found to be ineffective, due to physical obstructions and seabed physical properties.

Each acoustic method operated at a different frequency or broadcast direction, resulting in sensitivity to different structural elements: for instance, bathymetric sonar identified ripples on the seabed in Hammersley Inlet at the transition to Oakland Bay along transect lines, acoustic tomography identified recent sediment deposits overlying the bed surface along transect lines, and side-scan sonar identified large woody debris in wide swaths along transect lines.

4.1.1.1 Bathymetric Sonar

A bathymetric map (Figure 4-1) was constructed from approximately 10.6 miles of survey boat crossings (Figure 3-1). The map provides substantially higher resolution than existing nautical charts available from NOAA. A deep trough can be seen at the junction between Hammersley Inlet, Shelton Harbor, and Oakland Bay. The trough becomes shallower as it turns north along the northwest Oakland Bay shoreline.

The bathymetric survey revealed bedforms (i.e., ripples and dunes) at the intersection of Oakland Bay and Hammersley Inlet (Appendix E, Figure 4). The orientation of the bedforms (steep slopes on the “downstream” side) indicates water flow into Oakland Bay from Hammersley Inlet at depth and water flow out of Oakland Bay to Hammersley Inlet near the water surface. This is consistent with earlier hydrographic work in the study area (Ecology 2004a). No other bedforms were found in the study area; bedforms are discussed in detail in Appendix E.

4.1.1.2 Acoustic Tomography

Acoustic tomography survey results indicated a shallow sediment layer distinguished from a deeper, denser, more reflective layer. Differentiation between layers was defined by the speed of reflected acoustic signals broadcasted and received on the boat. The slow/fast response interface was consistent across Oakland Bay and Shelton Harbor (Appendix E, Figure 4 provides example instrument readouts showing this layer). The shallow layer was consistently observed across most of the study area, varying generally between 1 and 3 feet (0.3 and 0.9 meters) (Figures 4-2 and 4-3). The deeper, denser, reflective layer is representative of the pre-European development surface of Oakland Bay; the shallow, less consolidated layer consists of more recent sediments that have entered the bay since the onset of increased erosion from land disturbances in the watershed. Thicker recent deposits up to 8 feet (2.4 meters) are evident along the trough extending from Hammersley Inlet north into Oakland Bay. In nearshore areas where navigational hazards limited access the geophysical measurements were spatially interpolated to MLLW along the shoreline.

The figures indicate a missing surface layer (labeled as “undefined”) in Hammersley Inlet extending into southern Oakland Bay and the north portion of Shelton Harbor. The “undefined” sediment surface layering in Hammersley Inlet does not reflect the sedimentation pattern found across a majority of the study area in that the gravels and sands originate from shoreline erosion along the inlet, brought westward into Oakland Bay. Sedimentation across the north portion of

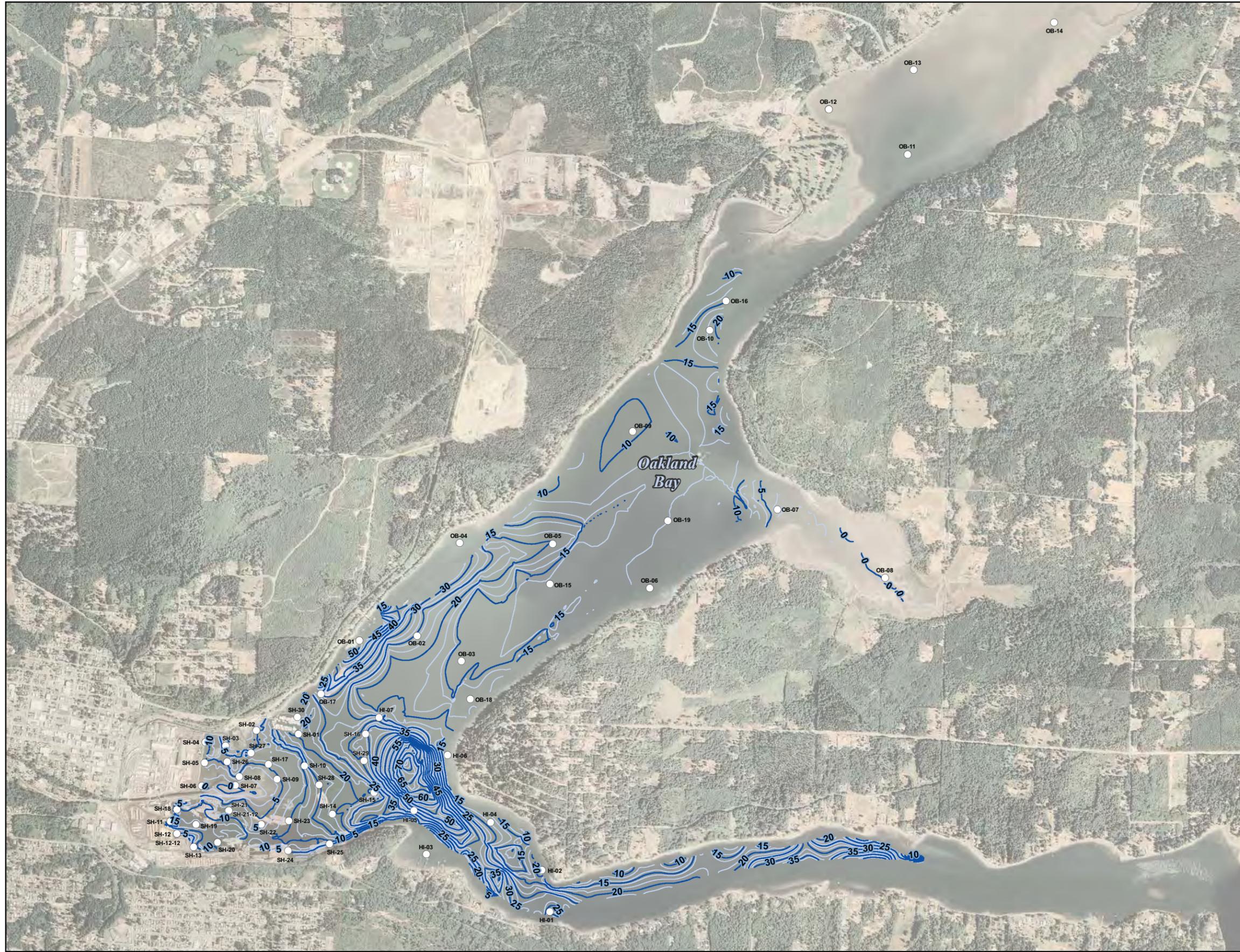
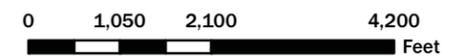


Figure 4-1. Bathymetric map of lower Oakland Bay, Shelton Harbor, and Hammersley Inlet.

Legend

- Sample location
- 5-foot bathymetric contour
- 2-foot bathymetric contour

Note: Bathymetric contours based on Mean Low Low Water elevations.



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Aerial: USDA 2006

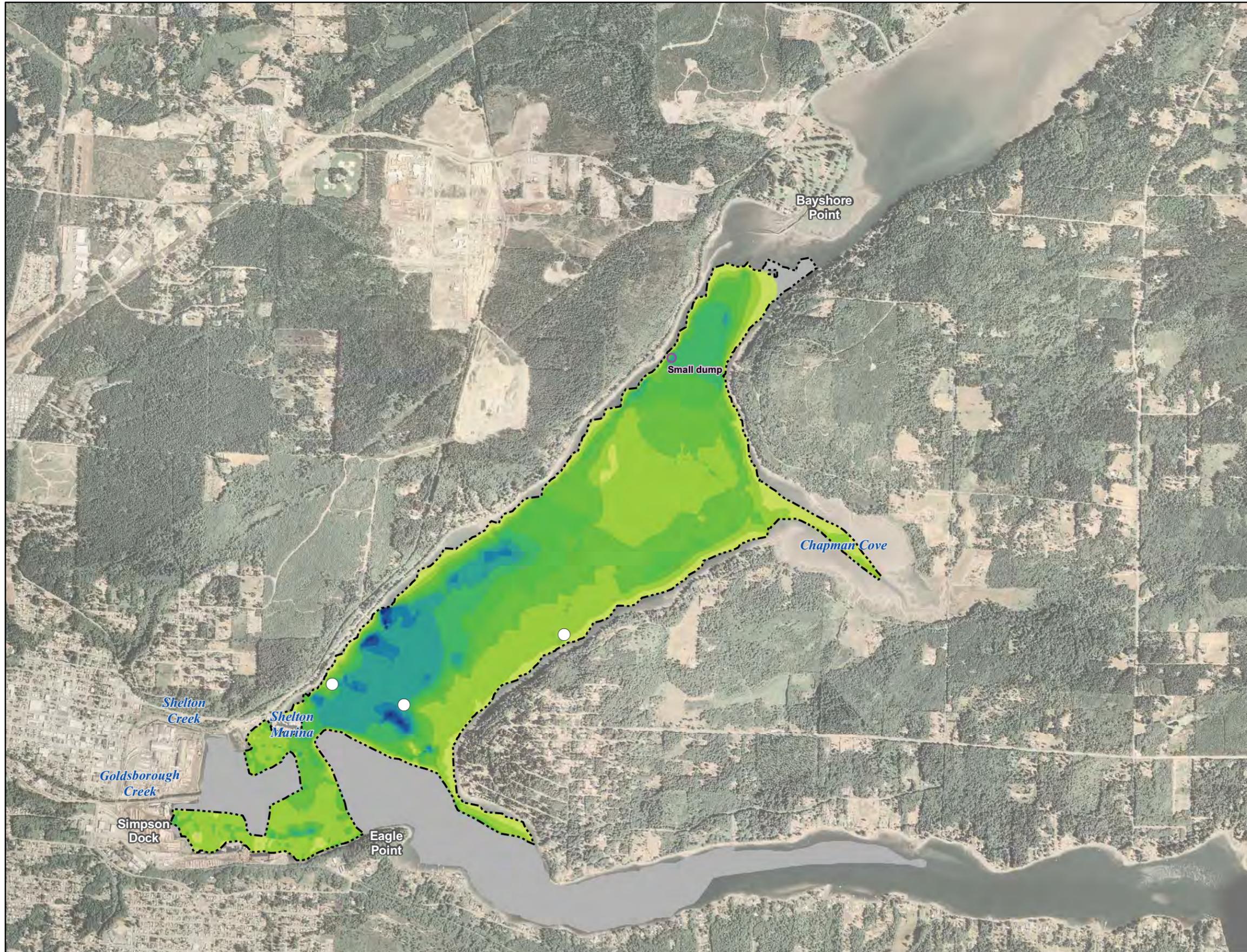
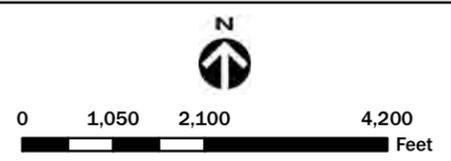


Figure 4-2.
Recent depositional layer thickness
in Oakland Bay and Hammersley
Inlet.

Legend

- Sunken logs
- ▭ Volume calculation extent
- Recent Sediment Deposition layer thickness (feet)**
- ▭ Undefined
- ▭ < 1
- ▭ 1 to 2
- ▭ 2 to 3
- ▭ 3 to 4
- ▭ 4 to 5
- ▭ 5 to 6
- ▭ 6 to 7
- ▭ 7 to 8
- ▭ 8 to 9
- ▭ > 9



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Aerial: USDA, 2006

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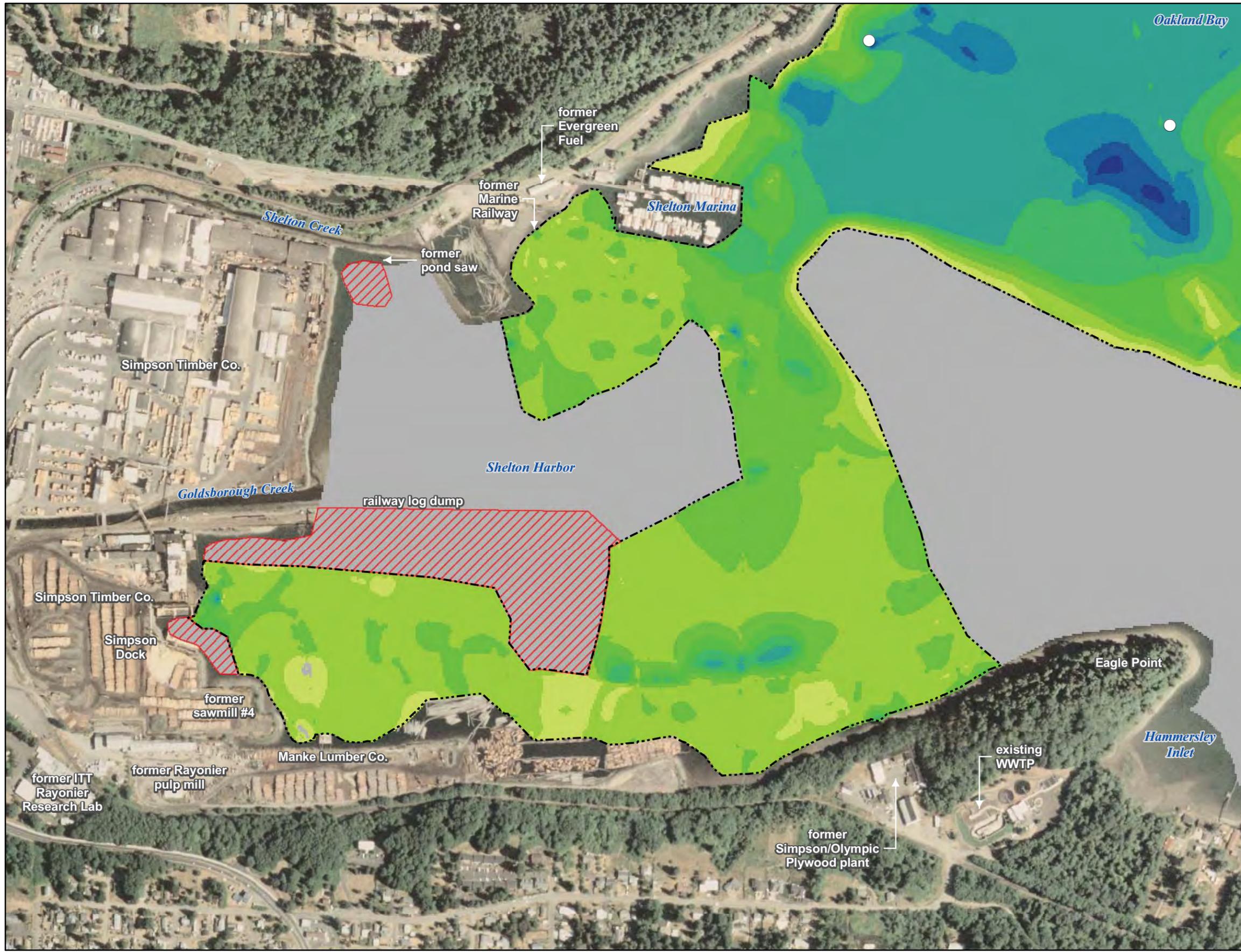


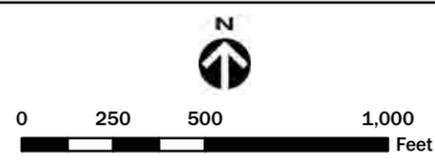
Figure 4-3.
Recent depositional layer thickness
in Shelton Harbor.

Legend

- Sunken logs
- ⋯ Volume calculation extent
- ▨ Estimated area of significant wood waste accumulation

Recent Sediment Deposition Layer Thickness

- ▭ Undefined
- ▭ < 1
- ▭ 1 to 2
- ▭ 2 to 3
- ▭ 3 to 4
- ▭ 4 to 5
- ▭ 5 to 6
- ▭ 6 to 7
- ▭ 7 to 8
- ▭ 8 to 9
- ▭ > 9



HERRERA
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Aerial: USDA, 2006

Produced By: GIS (RDR)
Project: K:\Projects\06-03386-007\Project\sediment_deposition_thickness-shelton.mxd

Shelton Harbor does not reflect conditions found throughout the rest of the bay either, due to significant sand and gravel input from Goldsborough and Shelton Creeks. This area is very shallow and includes a fair number of obstructions. Neither area could be adequately mapped using the survey methods employed for this study.

The areas identified with significant wood waste accumulations in Shelton Harbor (Figure 4-3) were estimated based on a combination of acoustic survey results and core sample information (discussed in Section 4.1.2). A significant build-up of wood in shallow sediment resulted in poor signal resolution, masking a clearly defined sediment layer interface. The areas of significant wood waste accumulation within Shelton Harbor are demarcated on the figure. Because the geophysical survey did not extend into the head of the bay, an area depicting significant wood waste, later identified solely by core information at location OB-12, was not estimated or represented on Figure 4-2.

4.1.1.3 *Side-Scan Sonar*

Side-scan sonar identified a few locations in Oakland Bay with multiple sunken logs; the aerial coverage of logs at these locations was not mapped (Figure 4-2). In Shelton Harbor, sunken logs appeared to be associated with historical or current log-rafting operations. Once again, individual occurrences were not mapped, but many logs were seen south of the railway log dump (Figure 4-3). In addition to the sunken logs, a small dump composed of old appliances and metallic debris was also discovered on the western shoreline, just below MLLW, about 3,300 feet (1,000 meters) southwest of Bayshore Point.

4.1.1.4 *Electrical Resistivity*

Resistivity measurements were attempted, but were found to be unusable due to a variety of issues: woody debris (e.g., twigs, logs, etc.) prohibited proper contact of equipment cable detectors with the seabed, the relatively limited thickness of the wood waste layer throughout the study area, and resistance of the wood-containing areas did not contrast well with wood-free sediment (increased porosity associated with the wood decreased resistance measurements in the seabed, counterbalancing the expected resistive characteristics of the wood). These conflicting processes made acoustic tools much more effective at characterizing wood waste content and extent.

4.1.1.5 *Induced Polarization*

Induced polarization measurements were attempted, but the same complicating factors as the resistivity technique were encountered and meaningful results could not be produced.

4.1.2 *Core Sample Information*

4.1.2.1 *Sediment Grain Size*

Sampling performed during this investigation generally involved collecting sediment from the top 7 to 12 feet (2.1 to 3.6 meters) of Shelton Harbor, Oakland Bay, and Hammersley Inlet (some

cores were shorter due to refusal). Descriptions of all 1 foot (0.3 meter) core sections collected at each location are provided in sediment core logs in Appendix B; additional information for each sample containerized and sent to the laboratories is provided in Appendix D.

Four typical sediment accumulation patterns were observed, based on collection of 51 sediment cores, with depths ranging from 2 feet to 12 feet (0.6 to 3.6 meters); multiple cores were collected at three locations. The most prevalent sediment type (63 percent) consisted of fine grain material throughout the core, grading from zones of clayey silt to silty clay, mostly in Oakland Bay. The second most prevalent sediment type (21 percent) consisted entirely of coarse material, mostly in Shelton Harbor creek deltas and Hammersley Inlet. The remaining sediment types (16 percent) included gradations from coarse to fine or fine to coarse grains, mostly in Shelton Harbor. A more detailed discussion of sediment grain size is found in Section 5.2.1.

4.1.2.2 *Wood Waste*

In Shelton Harbor, between two and seven sampling stations were established for each of the nine sampling strata established for the 1999 reconnaissance study (Ecology 2000) (see Figure 3-3). Wood waste content was estimated at each sampling station associated with a surface grab sample and sample core divided into 1 foot (0.3 meter) sections. Cores could not be collected at two stations along the southern shore of Shelton Harbor (SH-24 and SH-25) due to refusal (three attempts were made at both locations). The surface grab sample collected at SH-24 identified 50 percent wood as bark present, indicating the potential for enough large chunks of wood to block core tube advancement. The surface grab sample collected at SH-25 did not identify any wood present, indicating the potential for hard or cemented rock (i.e., cobbles, till) to block core tube advancement. Deep cores (10 to 12 feet [3.1 to 3.6 meters] deep) were collected following evidence of significant wood content at the base of the initial core attempts at SH-12, SH-21, and OB-12. This resulted in two core descriptions for each of these stations, separated from the initial cores by a few feet.

Wood was found intermixed with sediment at all depths sampled, categorized in four forms: bark, chips, fibers, and sawdust (see Appendix F). Large chunks of bark and chips were removed during sample processing, but wood fibers and sawdust were not and remained in samples delivered to the laboratories. Wood fibers appeared as thin strands, almost like thick hair.

Wood content was estimated by visual observation during sample processing. For core samples, this involved placing each 1 foot (0.3 meter) core section into a bowl for homogenization. Wood volume was estimated by considering a discernable presence as less than 1 percent, any amount above this was estimated on 5 percent intervals. Of the total number of each core section collected, the proportion with wood evident is provided below (note that fewer cores extended below the 3-4 foot interval, with very few deeper than 7 feet):

- **0-1 foot core sections:** 60 percent
- **1-2 foot core sections:** 60 percent
- **2-3 foot core sections:** 45 percent
- **3-4 foot core sections:** 30 percent

- **4-5 foot core sections:** 20 percent
- **5-6 foot core sections:** 30 percent
- **6-7 foot core sections:** 20 percent

When wood was found, it appeared as bark in 70 percent of the sampling stations, as chips in 26 percent of the stations, as fibers in 23 percent of the stations, and as sawdust in 6 percent of the stations. Approximately half of the time, only one form of wood was found in a core. Eleven of the cores containing wood had less than 1 percent noted in any core section, all others had at least 5 percent wood content estimated in at least one core section.

4.1.2.3 *Sediment Radioisotope Analyses*

Lead-210 and cesium-137 analyses are used to determine sediment accumulation rates, based on the decrease in lead-210 concentrations with depth. Cesium-137, associated with thermonuclear activity, began deposition in the 1950s and is used to establish a time benchmark position in the core (this is not necessarily a sharp delineation). This was done for cores collected at OB-15 and OB-16.

At SH-17, the abundance of sand and gravel made the detection of lead-210 difficult, since it is generally only found with fine-grained sediment (silt and clay). Because cesium-137 measurements also would be affected by the lack of fine-grained sediment, this analysis was not performed. The presence of sand and gravel throughout the core (resulting from relatively recent channelization of Goldsborough and Shelton Creeks) indicated that predevelopment sediment had not been reached, providing a non-radiological means of dating the sediment. Sediment radioisotope analysis is more fully discussed in Section 4.4. Analytical results for the three radioisotope cores collected are presented in Appendix I.

4.2 Sediment Chemistry

In Washington State, the use of the SMS is required by Chapter 173-204 WAC at all sediment cleanup sites. The standards were developed to reduce (and ultimately eliminate) adverse effects on biological resources and threats to human health from sediment contamination. The regulation includes both numeric and narrative standards used to reduce pollutant discharges and to provide a decision process for the cleanup of contaminated sediment sites.

The SMS contains two different levels of criteria for Puget Sound sediment. The Sediment Quality Standards (SQS) correspond to sediment quality that will result in no adverse effects to biological resources or significant risk to human health. The Cleanup Screening Levels (CSL) correspond to sediment quality that may result in minor adverse effects. The SQS serve as the cleanup objective for all cleanup actions. Sediment cleanup standards for site cleanup should be as close as practicable to the SQS standards, but may also consider cost and technical feasibility, as well as net environmental effects. The upper limit of site-specific cleanup standards correspond to the CSL.

The SMS includes numeric criteria for SQS and CSL levels of 47 chemicals and chemical groups, plus narrative criteria for other chemicals and deleterious substances. The SMS also contains biological effects criteria equivalent to the SQS (no adverse effects) and CSL (minor adverse effects). These biological effects are determined by laboratory toxicity tests or benthic abundance tests, as compared to reference sediment sites. The Oakland Bay study used laboratory toxicity tests to evaluate biological effects and confirm toxicity associated with chemistry results reported in the earlier Reconnaissance study (Ecology 2000).

Both chemical concentrations and biological effects tests are used to evaluate sediment quality, but the results of the biological effects tests can override the chemical concentration results. For chemicals that do not have numeric criteria, the biological effects test is the primary method to evaluate sediment quality for its effects on marine life.

Marine sediment investigations conducted under SMS rely on dry weight concentrations normalized by the amount of organic carbon present for many of the semi-volatile organic constituents (including PAHs, phthalates, chlorinated benzenes, PCBs, and other miscellaneous extractables). However, if organic carbon content is less than 0.5 percent or more than 4 percent, use of the carbon-normalized SQS and CSL criteria generally is not appropriate (Michelsen 1992). Eight sediment samples had reported organic carbon content of less than 0.5 percent and 17 samples had reported organic carbon content greater than 4.0 percent. Comparison of dry weight values to lowest apparent effects threshold (LAET) criteria is appropriate for these samples. In addition, some parameters that do not have SQS or CSL criteria (including chlorinated pesticides and some metals) can be compared to dry weight LAET criteria (PTI 1988).

Some parameters analyzed, such as dioxin/furan congeners and wood resin acids, do not have numerical criteria under the SMS, but do fall under the SMS narrative criteria. SMS narrative criteria include “other toxic or deleterious substances” (WAC 173-204-320) and are subject to evaluation by Ecology. In this study, dioxin/furan congener concentrations are reported in terms of the total toxic equivalent (TEQ), which sums all compound concentrations multiplied by their individual toxicity factors, as defined by the World Health Organization (Van den Berg et al. 2006). All dioxin/furan congeners were detected above the reporting limits in all but one sample. For the one dioxin/furan congener not detected above the reporting limit, one half of the reported value was added to the total TEQ value for that sample.

Appendix G presents chemistry results for this study; dry weight and carbon-normalized values are used to compare to SMS criteria. LAET values are also presented for comparison for chemicals without SMS criteria or for samples with organic carbon outside of the range for which organic-carbon normalizing is appropriate. Sediment samples with organic carbon content less than 0.5 percent or greater than 4.0 percent are indicated in Appendix G.

SMS criteria are applied to both detected and non-detected parameter values. No chemical SQS criteria were exceeded for detected parameters; however, several samples, though not detected, had detection limits that exceeded the SQS or CSL. The most common compounds exceeding SMS criteria due to high detection limits were hexachlorobenzene, 1,2,4-trichlorobenzene,

1,2-dichlorobenzene, and 2,4-dimethylphenol, none of which were detected above the reporting limits for any sample. With the exception of 2,4-dimethylphenol, which can be associated with wood waste, these compounds are not likely to be present in Oakland Bay based on known historic and current uses.

One sample exceeded the LAET criterion for one PAH compound – fluoranthene found at 2,000 microgram per kilogram ($\mu\text{g}/\text{kg}$) dry weight in sample SH-22-WS-00 (LAET criterion of 1,700 $\mu\text{g}/\text{kg}$ dry weight). The dry weight criterion was used for comparison, due to the elevated TOC content (5.77 percent) of the sample.

Conventional parameters (ammonia, total sulfides, TOC, TVS, grain size), TBT, total petroleum hydrocarbons, pesticides, dioxin/furan congeners, and resin acids do not have numerical SMS criteria, but were detected above reporting limits in several samples. No guaiacol compounds were detected above reporting limits. These results, in addition to parameters with numerical SMS criteria, are discussed in Section 5 – Data Interpretation.

Summary statistics were calculated for all parameters detected in one or more samples (Table 4-1). Results for diesel, gasoline, and guaiacols are not included on the table because there were no detections of those chemicals. If a relatively large number of non-detected values (i.e., censored values) existed for a parameter, summary statistics (mean and median) were calculated using regression on order statistics (CALTRANS 2001; Helsel 1990; Shumway and Azari 2000). Regression on order statistics develops probability plotting positions for each data point (censored and uncensored) based on ordering of the data. A least squares line is then fit by regressing the log transformed concentrations to the uncensored probability plotting positions that extend below the detection limit region of the graph. The censored data points are assigned concentrations for calculating summary statistics based on their probability plotting positions and the regression line equation. Summary statistics are then calculated based on the uncensored data points and the “filled-in” censored values. If data sets included less than 20 percent detections or had less than three detected samples, the median and mean were not calculated.

4.3 Sediment Toxicity

For this project, all surface sediment samples were submitted for toxicity (bioassay) testing at the same time as samples for chemical testing. The three reference sediment samples collected were analyzed in batches with project samples, as described above in Section 3.9.2. All bioassay tests were conducted under UV light.

Percent fines content, the total of the silt and clay grain size fractions, is used for pairing the appropriate reference sediment with a given test sediment. No attempt was made to match reference sample total organic carbon with that of the test samples, as wood waste in Oakland Bay can result in enriched organic carbon, which itself may be a factor in test results. TOC results for reference and test sediments are included in Table 4–2 for comparison. With the exception of a few samples, TOC results for reference sediments were generally significantly lower than those of the test sediments.

Table 4-1. Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Conventional Analyses							
Number of samples	27	25	17	17	6	6	3
Ammonia							
% Detected	100	92.0	100	94.1	100	100	100
Min. nondetect (mg/kg)	--	0.03	--	0.03	--	--	--
Max. nondetect (mg/kg)	--	0.03	--	0.03	--	--	--
Mean (mg/kg)	12.9	31.1 ^a	9.81	26.7 ^a	7.12	2.53	12.1
Median (mg/kg)	11.2	37.2	9.47	19.2	6.65	1.21	11.9
Min. detected (mg/kg)	2.76	0.19	4.28	0.18	5.68	0.77	9.95
Max. detected (mg/kg)	32.4	113	22.4	75.5	10.1	7.75	14.4
Max. detected location	SH-18	SH-13	OB-18	OB-09	HI-04	HI-03	RF-03
Sulfide							
% Detected	96.3	96.0	94.1	88.2	100	66.7	100
Min. nondetect (mg/kg)	0.01	0.01	0.01	0.01	--	0.01	--
Max. nondetect (mg/kg)	0.01	0.01	0.01	0.01	--	0.01	--
Mean (mg/kg)	661 ^a	194 ^a	666 ^a	181 ^a	82.3	32.0 ^a	168
Median (mg/kg)	518	123	685	141	13.7	3.95	166
Min. detected (mg/kg)	1.42	14.5	6.83	28.6	1.3	3.41	16.7
Max. detected (mg/kg)	1,890	759	1,530	555	258	179	320
Max. detected location	SH-21	SH-21	OB-09	OB-05	HI-06	HI-06	RF-01
Total Organic Carbon							
% Detected	100	100	100	100	100	100	100
Min. nondetect (%)	--	--	--	--	--	--	--
Max. nondetect (%)	--	--	--	--	--	--	--
Mean (%)	3.20	3.03	2.40	2.00	1.09	0.500	0.500
Median (%)	2.60	2.47	2.39	2.09	0.740	0.539	0.589
Min. detected (%)	0.511	0.153	0.878	0.045	0.571	0.206	0.273
Max. detected (%)	11.0	11.1	4.68	4.74	2.43	0.829	0.639
Max. detected location	SH-13	SH-21	OB-06	OB-18	HI-06	HI-02	RF-01
Total Volatile Solids							
Number of samples	13	11	3	3	0	0	3
% Detected	100	100	100	100	NA	NA	100
Min. nondetect (%)	--	--	--	--	NA	NA	--
Max. nondetect (%)	--	--	--	--	NA	NA	--
Mean (%)	10.6	12.6	7.67	10.7	NA	NA	2.00
Median (%)	10.8	8.62	9.25	12.4	NA	NA	2.26
Min. detected (%)	1.55	1.85	4.41	6.15	NA	NA	1.13
Max. detected (%)	19.7	39.5	9.35	13.6	NA	NA	2.60
Max. detected location	SH-22	SH-21	OB-18	OB-18	NA	NA	RF-01

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Metals							
Number of samples	26	25	17	3	6	0	3
Antimony							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (mg/kg)	--	--	--	--	--	NA	--
Max. nondetect (mg/kg)	--	--	--	--	--	NA	--
Mean (mg/kg)	0.29	0.28	0.26	0.34	0.13	NA	--
Median (mg/kg)	0.27	0.22	0.26	0.39	0.14	NA	--
Min. detected (mg/kg)	0.1	0.065	0.12	0.19	0.074	NA	0.10
Max. detected (mg/kg)	0.83	0.69	0.39	0.43	0.16	NA	0.16
Max. detected location	SH-11	SH-12	OB-05	OB-19	HI-03	NA	RF-01 / RF-02
Arsenic							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (mg/kg)	--	--	--	--	--	NA	--
Max. nondetect (mg/kg)	--	--	--	--	--	NA	--
Mean (mg/kg)	5.8	4.3	5.6	6.8	3.8	NA	2.6
Median (mg/kg)	6.2	4.1	5.3	7.3	3.6	NA	3.1
Min. detected (mg/kg)	2.1	1.3	3.3	4.2	2.2	NA	1.5
Max. detected (mg/kg)	8.5	9.1	7.3	9.0	6.3	NA	3.2
Max. detected location	SH-19	SH-12	OB-06	OB-19	HI-06	NA	RF-02
Cadmium							
% Detected	100	100	100	100	83.3	NA	100
Min. nondetect (mg/kg)	--	--	--	--	0.11	NA	--
Max. nondetect (mg/kg)	--	--	--	--	0.11	NA	--
Mean (mg/kg)	0.76	0.65	0.56	0.74	0.25 ^a	NA	0.31
Median (mg/kg)	0.71	0.62	0.53	0.77	0.15	NA	0.41
Min. detected (mg/kg)	0.1	0.15	0.20	0.46	0.12	NA	0.098
Max. detected (mg/kg)	1.8	1.8	0.96	1.0	0.63	NA	0.42
Max. detected location	SH-18	SH-18	OB-06	OB-19	HI-03	NA	RF-02
Chromium							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (mg/kg)	--	--	--	--	--	NA	--
Max. nondetect (mg/kg)	--	--	--	--	--	NA	--
Mean (mg/kg)	41	41.2	37	41	24	NA	20
Median (mg/kg)	41	40	36	45	24	NA	23
Min. detected (mg/kg)	20	23	24	28	17	NA	12
Max. detected (mg/kg)	62	65	48	50	29	NA	26
Max. detected location	SH-11	SH-11	OB-18	OB-19	HI-03	NA	RF-01

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Copper							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (mg/kg)	--	--	--	--	--	NA	--
Max. nondetect (mg/kg)	--	--	--	--	--	NA	--
Mean (mg/kg)	46	47	30	--	14	NA	11
Median (mg/kg)	42	44	31	--	14	NA	14
Min. detected (mg/kg)	10	15	18	22	9.9	NA	4.3
Max. detected (mg/kg)	120	110	47	50	18	NA	16
Max. detected location	SH-11	SH-12	OB-06	OB-18 / OB-19	HI-03	NA	RF-01
Lead							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (mg/kg)	--	--	--	--	--	NA	--
Max. nondetect (mg/kg)	--	--	--	--	--	NA	--
Mean (mg/kg)	12	13	9.4	14	4.8	NA	3.9
Median (mg/kg)	11	9.2	10	17	3.0	NA	4.5
Min. detected (mg/kg)	2.4	2.0	4.1	4.9	2.2	NA	2.6
Max. detected (mg/kg)	43	47	15	20	14	NA	4.6
Max. detected location	SH-11	SH-11	OB-06	OB-19	HI-03	NA	RF-01
Mercury							
% Detected	92.6	72.0	100	66.7	83.3	NA	100
Min. nondetect (mg/kg)	0.0073	0.0064	--	0.125	0.0075	NA	--
Max. nondetect (mg/kg)	0.0078	0.184	--	0.125	0.0075	NA	--
Mean (mg/kg)	0.076 ^a	0.078 ^a	0.047	--	0.016 ^a	NA	0.012
Median (mg/kg)	0.059 ^a	0.052 ^a	0.043	--	0.015	NA	0.012
Min. detected (mg/kg)	0.012	0.012	0.017	0.087	0.0075	NA	0.0081
Max. detected (mg/kg)	0.19	0.29	0.086	0.16	0.037	NA	0.016
Max. detected location	SH-11	SH-12	OB-12	OB-19	HI-03	NA	RF-02
Nickel							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (mg/kg)	--	--	--	--	--	NA	--
Max. nondetect (mg/kg)	--	--	--	--	--	NA	--
Mean (mg/kg)	35	35	32	37	26	NA	21
Median (mg/kg)	36	35	31	40	24	NA	25
Min. detected (mg/kg)	21	22	21	29	20	NA	11
Max. detected (mg/kg)	46	45	44	42	35	NA	28
Max. detected location	SH-18	SH-11	OB-18	OB-19	HI-02	NA	RF-01

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Silver							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (mg/kg)	--	--	--	--	--	NA	--
Max. nondetect (mg/kg)	--	--	--	--	--	NA	--
Mean (mg/kg)	0.12	0.13	0.13	0.18	0.035	NA	0.054
Median (mg/kg)	0.11	0.098	0.13	0.19	0.025	NA	0.064
Min. detected (mg/kg)	0.017	0.02	0.037	0.07	0.022	NA	0.023
Max. detected (mg/kg)	0.23	0.55	0.34	0.28	0.060	NA	0.075
Max. detected location	SH-18	SH-12	OB-05	OB-19	HI-03	NA	RF-01
Zinc							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (mg/kg)	--	--	--	--	--	NA	--
Max. nondetect (mg/kg)	--	--	--	--	--	NA	--
Mean (mg/kg)	77	62	69	67	37	NA	27
Median (mg/kg)	76	59	70	74	34	NA	32
Min. detected (mg/kg)	29	30	43	41	28	NA	14
Max. detected (mg/kg)	130	130	99	87	55	NA	36
Max. detected location	SH-18	SH-12	OB-18	OB-19	HI-03	NA	RF-01
Butyltins							
Number of samples	3	3	0	0	0	0	3
Butyltin ion							
% Detected	33.3	0	NA	NA	NA	NA	0
Min. nondetect (µg/kg)	3.6	3.9	NA	NA	NA	NA	3.4
Max. nondetect (µg/kg)	3.9	3.9	NA	NA	NA	NA	3.6
Mean (µg/kg)	--	--	NA	NA	NA	NA	--
Median (µg/kg)	--	--	NA	NA	NA	NA	--
Min. detected (µg/kg)	8.0	--	NA	NA	NA	NA	--
Max. detected (µg/kg)	8.0	--	NA	NA	NA	NA	--
Max. detected location	SH-02	--	NA	NA	NA	NA	--
Dibutyltin ion							
% Detected	33.3	0	NA	NA	NA	NA	0
Min. nondetect (µg/kg)	2.8	2.7	NA	NA	NA	NA	2.6
Max. nondetect (µg/kg)	3.0	3.0	NA	NA	NA	NA	2.8
Mean (µg/kg)	--	--	NA	NA	NA	NA	--
Median (µg/kg)	--	--	NA	NA	NA	NA	--
Min. detected (µg/kg)	30	--	NA	NA	NA	NA	--
Max. detected (µg/kg)	30	--	NA	NA	NA	NA	--
Max. detected location	SH-02	--	NA	NA	NA	NA	--