SEDIMENT INVESTIGATION REPORT

Oakland Bay Sediment Characterization Study, Mason County, Washington

DEPARTMENT OF
ECOLOGY
State of Washington

Prepared for

Washington Department of Ecology
Toxics Cleanup Program
Southwest Regional Office

November 2010

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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 lead 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

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

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

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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. Dichlordiphenyldichloroethylene (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, algaecides, 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 crenulating 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

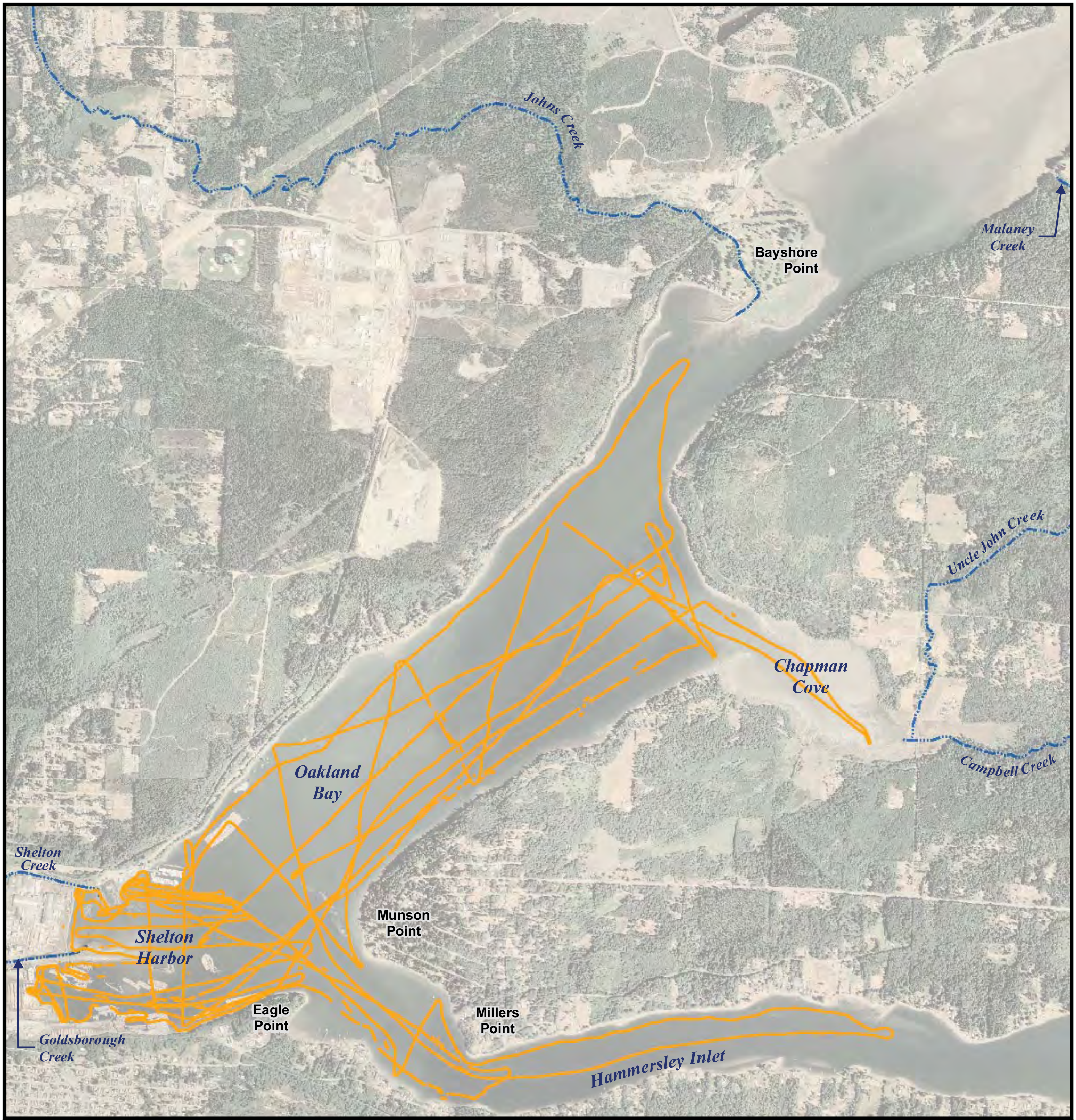
Field investigation involved a visual inspection of the site and surrounding area, conducting a series of geophysical surveys using equipment mounted on a boat, and collecting sediment surface grab and core samples from boats. Five different geophysical data collection methods and two types of sedimentation 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 COPCs (no dioxins/furans). Samples collected at designated wood waste locations were analyzed for wood waste constituents in addition to industrial COPCs. 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.

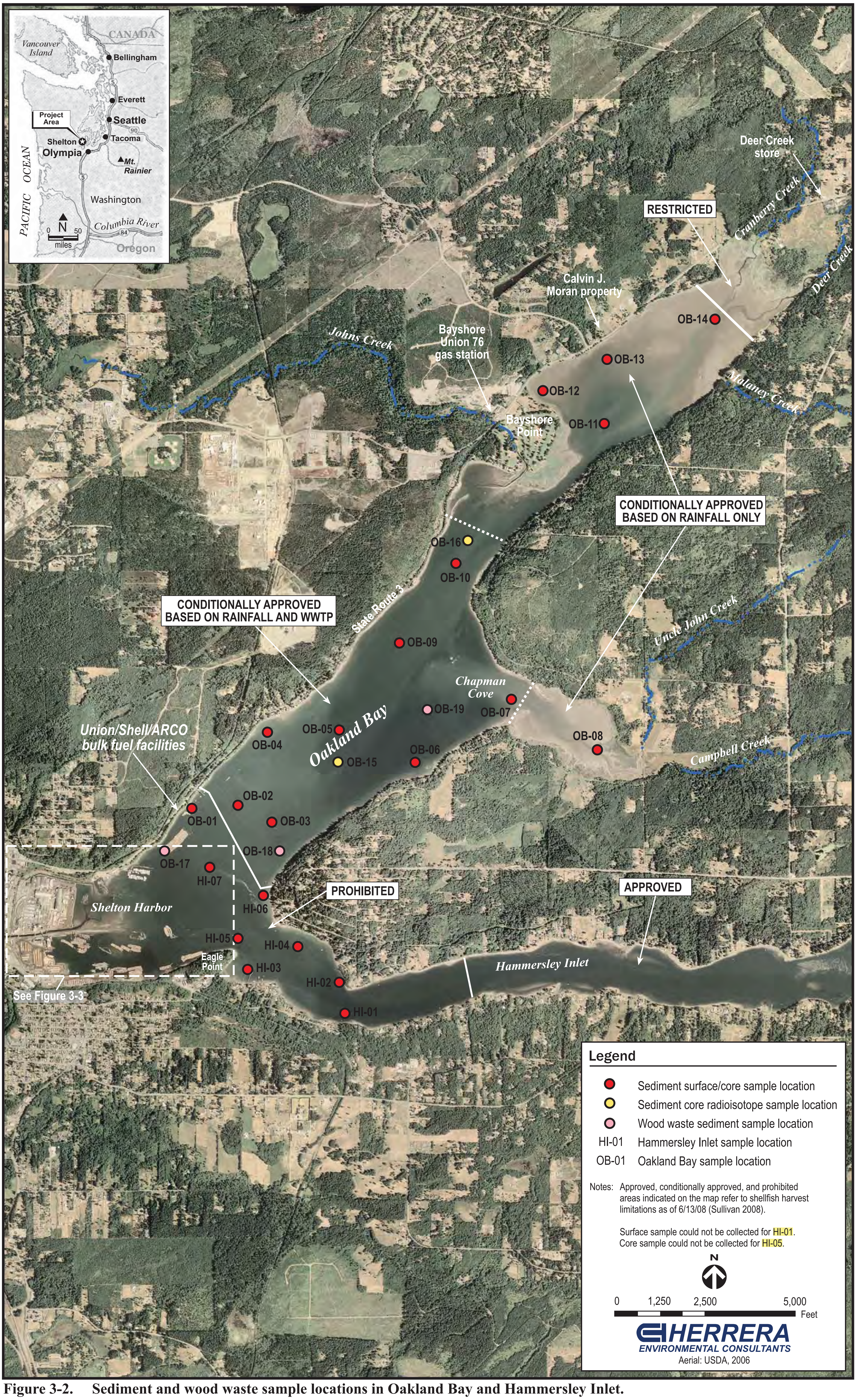
Three designated cores were analyzed for radioisotope constituents; every third 0.8 inch (2 cm) core section was initially analyzed for lead-210 and the remainder archived for future cesium-137 analysis, which was performed on two cores.

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



Notes: Approved, conditionally approved, and prohibited areas indicated on the map refer to shellfish harvest limitations as of 6/13/08 (Sullivan 2008).

Surface sample could not be collected for HI-01.
Core sample could not be collected for HI-05.

04-28-09/sm/HEC-R/06-03386-007-003-001/Sed Investigation Rpt

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

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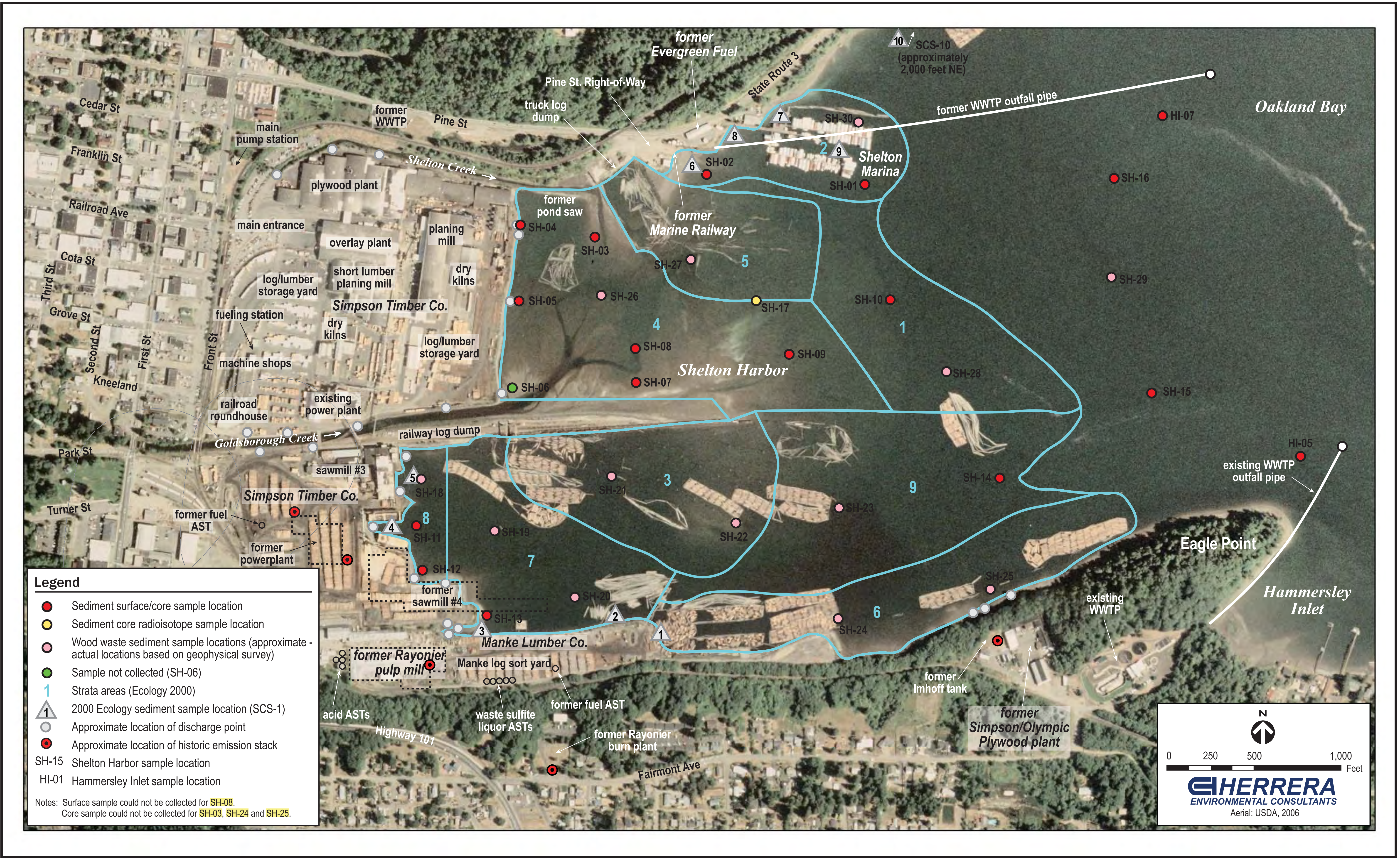


Figure 3-3. Sediment and wood waste sample locations in Shelton Harbor, Shelton, Washington.

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 4ºC, 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 (juvenal 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.

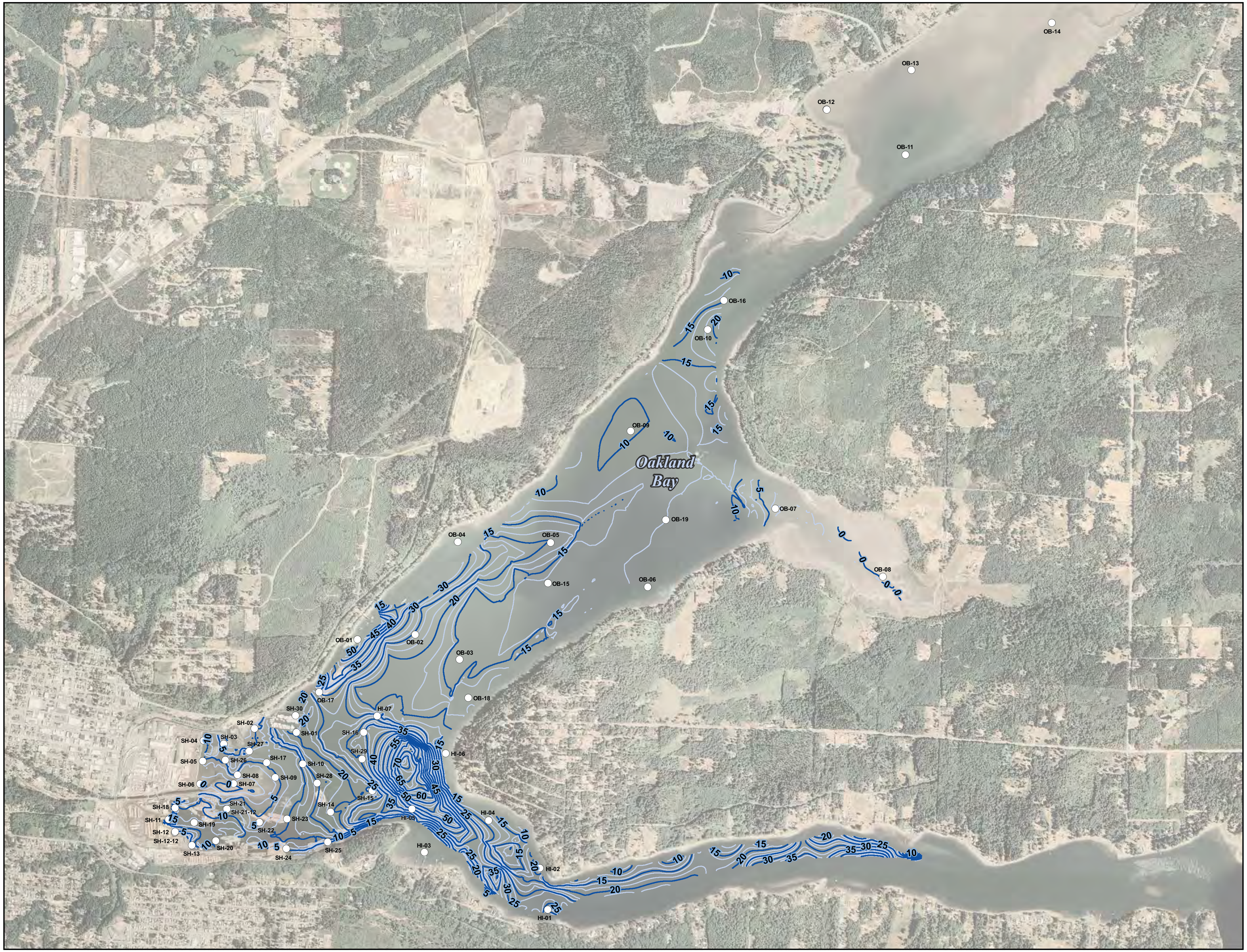
The bathymetric survey revealed bedforms (i.e., ripples and dunes) at the intersection of Oakland Bay and Hammersley Inlet (Appendix E, Figure 4). The orientation of the bedforms (steep slopes on the “downstream” side) indicates water flow into Oakland Bay from Hammersley Inlet at depth and water flow 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.

N

0 1,050 2,100 4,200 Feet

HERRERA
ENVIRONMENTAL CONSULTANTS

Aerial: USDA 2006

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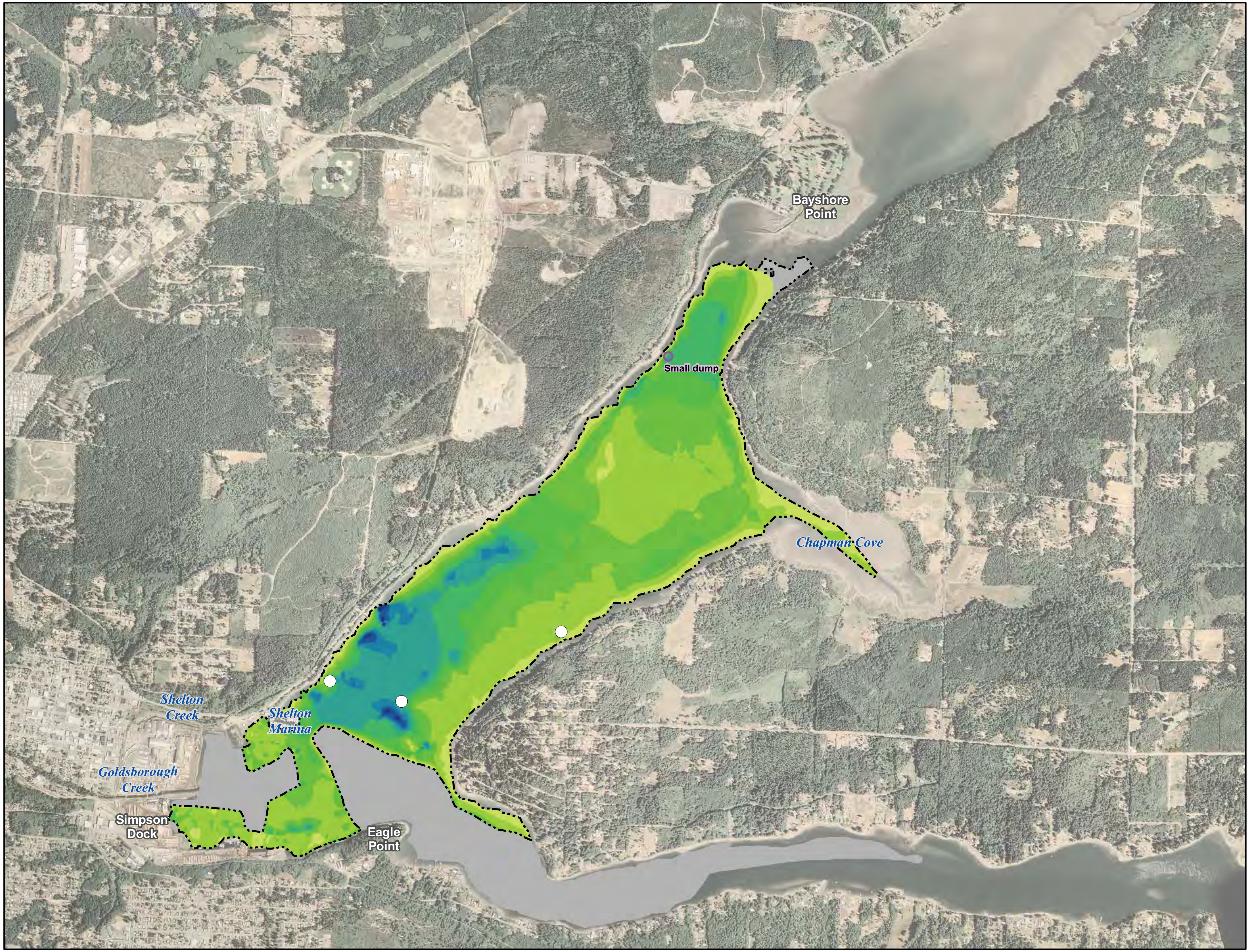
Figure 4-2.
Recent depositional layer thickness in Oakland Bay and Hammersley Inlet.



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

N

0 1,050 2,100 4,200
Feet

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Aerial: USDA, 2006

Produced By: GIS (RDR)
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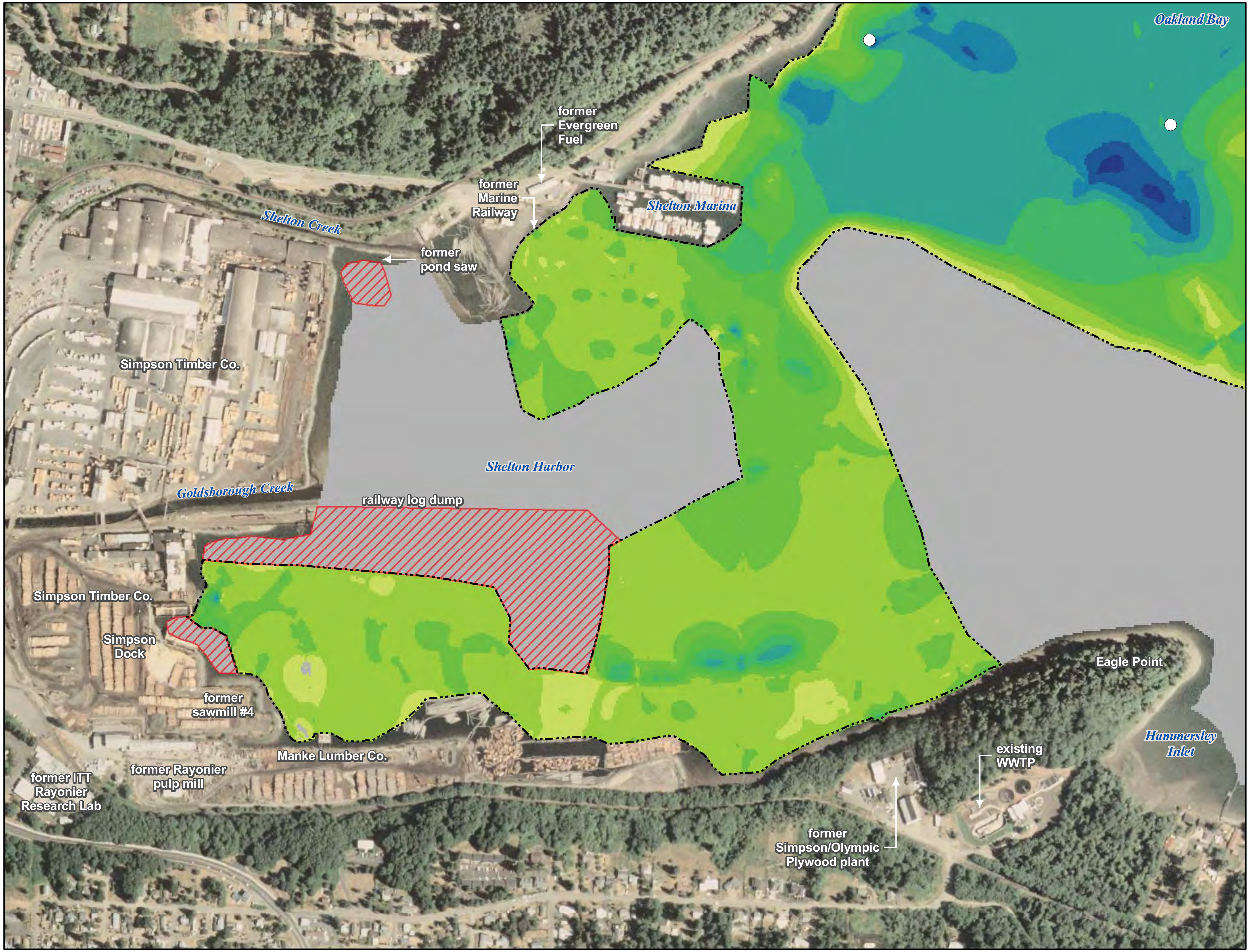
Figure 4-3.
Recent depositional layer thickness in Shelton Harbor.



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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-dichlrorobenzene, 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 (µg/kg) dry weight in sample SH-22-WS-00 (LAET criterion of 1,700 µg/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.

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	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.

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	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.

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	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.

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	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	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Tributyltin ion							
% Detected	33.3	0	NA	NA	NA	NA	0
Min. nondetect (µg/kg)	1.6	1.5	NA	NA	NA	NA	1.5
Max. nondetect (µg/kg)	1.7	1.7	NA	NA	NA	NA	1.6
Mean (µg/kg)	--	--	NA	NA	NA	NA	--
Median (µg/kg)	--	--	NA	NA	NA	NA	--
Min. detected (µg/kg)	13	--	NA	NA	NA	NA	--
Max. detected (µg/kg)	13	--	NA	NA	NA	NA	--
Max. detected location	SH-02	--	NA	NA	NA	NA	--
Low molecular weight PAHs							
Number of samples	27	25	17	3	6	0	3
Total LPAHs							
% Detected	66.7	72.0	11.8	0	0	NA	0
Min. nondetect (mg/kg OC)	0.39	0.57	0.43	0.42	0.78	NA	3.1
Max. nondetect (mg/kg OC)	3.9	13	2.3	44	3.5	NA	7.3
Mean (mg/kg OC)	4.3 [a]	2.9 [a]	--	--	--	NA	--
Median (mg/kg OC)	1.1 [a]	1.5 [a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.38	0.20	1.5	--	--	NA	--
Max. detected (mg/kg OC)	53	16	2.5	--	--	NA	--
Max. detected location	SH-11	SH-18	OB-07	--	--	NA	--
Acenaphthene							
% Detected	11.1	12.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.074	0.12	0.17	0.17	0.32	NA	1.3
Max. nondetect (mg/kg OC)	20	5.3	0.92	18	1.4	NA	2.9
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.21	0.24	--	--	--	NA	--
Max. detected (mg/kg OC)	0.53	1.4	--	--	--	NA	--
Max. detected location	SH-02	SH-12	--	--	--	NA	--
Acenaphthylene							
% Detected	18.5	8.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.15	0.12	0.18	0.18	0.34	NA	1.3
Max. nondetect (mg/kg OC)	20	5.6	0.98	19	1.5	NA	3.1
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.11	0.21	--	--	--	NA	--
Max. detected (mg/kg OC)	1.3	0.68	--	--	--	NA	--
Max. detected location	SH-02	SH-12	--	--	--	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Anthracene							
% Detected	29.6	20.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.14	0.11	0.16	0.16	0.31	NA	1.2
Max. nondetect (mg/kg OC)	1.5	5.0	0.88	17	1.3	NA	2.7
Mean (mg/kg OC)	0.49[a]	0.39[a]	--	--	--	NA	--
Median (mg/kg OC)	0.16[a]	0.20[a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.34	0.59	--	--	--	NA	--
Max. detected (mg/kg OC)	5.3	2.2	--	--	--	NA	--
Max. detected location	SH-02	SH-12	--	--	--	NA	--
Fluorene							
% Detected	18.5	12.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.16	0.13	0.19	0.19	0.36	NA	1.4
Max. nondetect (mg/kg OC)	1.5	5.0	1.0	20	1.5	NA	3.2
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.14	0.22	--	--	--	NA	--
Max. detected (mg/kg OC)	1.9	1.7	--	--	--	NA	--
Max. detected location	SH-02	SH-18	--	--	--	NA	--
Naphthalene							
% Detected	22.2	28.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.15	0.12	0.18	0.18	0.34	NA	1.3
Max. nondetect (mg/kg OC)	1.7	5.6	0.98	19	1.5	NA	3.1
Mean (mg/kg OC)	0.29[a]	0.49[a]	--	--	--	NA	--
Median (mg/kg OC)	0.15[a]	0.23[a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.13	0.35	--	--	--	NA	--
Max. detected (mg/kg OC)	1.9	3.0	--	--	--	NA	--
Max. detected location	SH-11	SH-18	--	--	--	NA	--
Phenanthrene							
% Detected	66.7	72.0	11.8	0	0	NA	0
Min. nondetect (mg/kg OC)	0.16	0.24	0.18	0.18	0.33	NA	1.3
Max. nondetect (mg/kg OC)	1.6	5.4	0.94	18	1.4	NA	3.0
Mean (mg/kg OC)	1.7[a]	1.9[a]	--	--	--	NA	--
Median (mg/kg OC)	0.74[a]	1.0[a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.38	0.20		--	--	NA	--
Max. detected (mg/kg OC)	15	10	1.5	--	--	NA	--
Max. detected location	SH-02	SH-07	OB-04	--	--	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
High molecular weight PAHs							
Number of samples	27	25	17	3	6	0	3
Total HPAHs							
% Detected	88.9	80.0	41.2	66.7	16.7	NA	0
Min. nondetect (mg/kg OC)	1.4	0.57	0.43	1.1	0.78	NA	3.1
Max. nondetect (mg/kg OC)	3.9	13	2.3	1.1	3.5	NA	7.3
Mean (mg/kg OC)	16[a]	21[a]	1.7[a]	--	--	NA	--
Median (mg/kg OC)	9.3[a]	7.9[a]	0.56[a]	--	--	NA	--
Min. detected (mg/kg OC)	1.6	1.3	0.31	0.51	3.0	NA	--
Max. detected (mg/kg OC)	90	181	15	98	3.0	NA	--
Max. detected location	SH-22	SH-07	OB-07	OB-19	HI-03	NA	--
Benzo(a)anthracene							
% Detected	66.7	64.0	11.8	0	0	NA	0
Min. nondetect (mg/kg OC)	0.11	0.13	0.12	0.12	0.23	NA	0.92
Max. nondetect (mg/kg OC)	1.1	3.8	0.67	13	1.0	NA	2.1
Mean (mg/kg OC)	1.4[a]	1.8[a]	--	--	--	NA	--
Median (mg/kg OC)	0.82[a]	0.70[a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.54	0.22	0.70	--	--	NA	--
Max. detected (mg/kg OC)	6.9	15	1.8	--	--	NA	--
Max. detected location	SH-02	SH-07	OB-07	--	--	NA	--
Benzo(a)pyrene							
% Detected	66.7	64.0	5.9	33.3	0	NA	0
Min. nondetect (mg/kg OC)	0.16	0.18	0.17	0.17	0.32	NA	1.3
Max. nondetect (mg/kg OC)	1.6	5.3	0.92	0.46	1.4	NA	2.9
Mean (mg/kg OC)	1.5[a]	2.3[a]	--	--	--	NA	--
Median (mg/kg OC)	0.89[a]	0.90[a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.54	0.32	1.5	47	--	NA	--
Max. detected (mg/kg OC)	7.3	23	1.5	47	--	NA	--
Max. detected location	SH-02	SH-07	OB-07	OB-19	--	NA	--
Benzo(g,h,i)perylene							
% Detected	48.1	44.0	0	33.3	0	NA	0
Min. nondetect (mg/kg OC)	0.12	0.10	0.14	0.14	0.27	NA	1.0
Max. nondetect (mg/kg OC)	1.3	4.4	0.76	0.38	1.2	NA	2.4
Mean (mg/kg OC)	0.62[a]	1.4[a]	--	--	--	NA	--
Median (mg/kg OC)	0.39[a]	0.29[a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.21	0.42	--	51	--	NA	--
Max. detected (mg/kg OC)	2.7	22	--	51	--	NA	--
Max. detected location	SH-02	SH-07	--	OB-19	--	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Chrysene							
% Detected	85.2	68.0	29.4	0	16.7	NA	0
Min. nondetect (mg/kg OC)	0.48	0.19	0.14	0.14	0.26	NA	1.0
Max. nondetect (mg/kg OC)	1.3	4.3	0.78	15	1.1	NA	2.4
Mean (mg/kg OC)	2.6 [a]	3.1 [a]	0.37 [a]	--	--	NA	--
Median (mg/kg OC)	1.6 [a]	1.1 [a]	0.21 [a]	--	--	NA	--
Min. detected (mg/kg OC)	0.503	0.32	0.49	--	0.83	NA	--
Max. detected (mg/kg OC)	14	29	2.1	--	0.83	NA	--
Max. detected location	SH-22	SH-07	OB-07	--	HI-03	NA	--
Dibenz(a,h)anthracene							
% Detected	11.1	0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.076	0.12	0.18	0.18	0.34	NA	1.3
Max. nondetect (mg/kg OC)	1.3	5.6	1.0	19	1.5	NA	3.0
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.31	--	--	--	--	NA	--
Max. detected (mg/kg OC)	0.57	--	--	--	--	NA	--
Max. detected location	SH-02	--	--	--	--	NA	--
Fluoranthene							
% Detected	88.9	76.0	23.5	33.3	16.7	NA	0
Min. nondetect (mg/kg OC)	0.57	0.22	0.17	0.44	0.31	NA	1.2
Max. nondetect (mg/kg OC)	1.5	5.1	1.4	17	1.4	NA	2.8
Mean (mg/kg OC)	4.3 [a]	5.0 [a]	0.37 [a]	--	--	NA	--
Median (mg/kg OC)	2.3 [a]	2.2 [a]	0.076 [a]	--	--	NA	--
Min. detected (mg/kg OC)	0.54	0.42	0.31	0.23	1.1	NA	--
Max. detected (mg/kg OC)	35	33	3.6	0.23	1.1	NA	--
Max. detected location	SH-22	SH-07	OB-07	OB-18	HI-03	NA	--
Indeno(1,2,3-cd)pyrene							
% Detected	37.0	20.0	5.9	0	0	NA	0
Min. nondetect (mg/kg OC)	0.15	0.12	0.18	0.18	0.34	NA	1.3
Max. nondetect (mg/kg OC)	1.6	5.6	0.97	19	1.5	NA	3.1
Mean (mg/kg OC)	0.45 [a]	0.37 [a]	--	--	--	NA	--
Median (mg/kg OC)	0.28 [a]	0.080 [a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.22	0.30	1.1	--	--	NA	--
Max. detected (mg/kg OC)	2.4	5.6	1.1	--	--	NA	--
Max. detected location	SH-02	SH-07	OB-02	--	--	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Pyrene							
% Detected	88.9	80.0	29.4	33.3	16.7	NA	0
Min. nondetect (mg/kg OC)	0.56	0.22	0.16	0.43	0.31	NA	1.2
Max. nondetect (mg/kg OC)	1.5	5.0	0.88	17	1.3	NA	2.8
Mean (mg/kg OC)	3.6 [a]	4.8 [a]	0.50 [a]	--	--	NA	--
Median (mg/kg OC)	2.2 [a]	2.3 [a]	0.20 [a]	--	--	NA	--
Min. detected (mg/kg OC)	0.54	0.45	0.61	0.27	1.1	NA	--
Max. detected (mg/kg OC)	17	33	3.3	0.27	1.1	NA	--
Max. detected location	SH-22	SH-07	OB-07	OB-18	HI-03	NA	--
Total benzofluoranthenes							
% Detected	70.4	56.0	5.9	0	0	NA	0
Min. nondetect (mg/kg OC)	0.39	0.46	0.43	0.42	0.78	NA	3.1
Max. nondetect (mg/kg OC)	3.9	13	2.3	44	3.5	NA	7.3
Mean (mg/kg OC)	3.1 [a]	3.6 [a]	--	--	--	NA	--
Median (mg/kg OC)	1.9 [a]	1.7 [a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.44	0.44	2.8	--	--	NA	--
Max. detected (mg/kg OC)	13	22	2.8	--	--	NA	--
Max. detected location	SH-22	SH-07	OB-07	--	--	NA	--
Other SVOCs							
Number of samples	27	25	17	3	6	0	3
Bis(2-ethylhexyl)phthalate							
% Detected	48.1	40.0	17.6	0	0	NA	33.3
Min. nondetect (mg/kg OC)	0.20	0.16	0.31	0.23	0.45	NA	1.9
Max. nondetect (mg/kg OC)	2.2	4.7	1.3	24	1.9	NA	4.0
Mean (mg/kg OC)	0.70 [a]	1.2 [a]	--	--	--	NA	--
Median (mg/kg OC)	0.48 [a]	0.67 [a]	--	--	--	NA	--
Min. detected (mg/kg OC)	0.14	0.44	0.65	--	--	NA	3.9
Max. detected (mg/kg OC)	3.2	13	1.7	--	--	NA	3.9
Max. detected location	SH-10	SH-26	OB-19	--	--	NA	RF-01
Butylbenzylphthalate							
% Detected	3.7	0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.10	0.16	0.24	0.23	0.45	NA	1.7
Max. nondetect (mg/kg OC)	2.2	7.2	1.3	24	1.9	NA	4.0
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	1.0	--	--	--	--	NA	--
Max. detected (mg/kg OC)	1.0	--	--	--	--	NA	--
Max. detected location	SH-03	--	--	--	--	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Dibenzofuran							
% Detected	0	12.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.067	0.11	0.16	0.16	0.30	NA	1.2
Max. nondetect (mg/kg OC)	1.4	4.7	0.85	17	1.2	NA	2.7
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	--	0.26	--	--	--	NA	--
Max. detected (mg/kg OC)	--	1.2	--	--	--	NA	--
Max. detected location	--	SH-18	--	--	--	NA	--
4-Methylphenol							
% Detected	33.3	24.0	11.8	0	16.7	NA	0
Min. nondetect (µg/kg)	12	12	12	13	12	NA	12
Max. nondetect (µg/kg)	13	32	13	13	13	NA	13
Mean (µg/kg)	30[a]	31[a]	--	--	--	NA	--
Median (µg/kg)	5.1[a]	2.7[a]	--	--	--	NA	--
Min. detected (µg/kg)	18	18	43	--	140	NA	--
Max. detected (µg/kg)	410	320	53	--	140	NA	--
Max. detected location	SH-11	SH-11	OB-10	--	HI-06	NA	--
Phenol							
% Detected	22.2	20.0	23.5	33.3	50.0	NA	33.3
Min. nondetect (µg/kg)	13	13	13	13	13	NA	13
Max. nondetect (µg/kg)	14	41	14	14	13	NA	14
Mean (µg/kg)	11[a]	14[a]	17[a]	--	89[a]	NA	--
Median (µg/kg)	4.2[a]	10[a]	2.2[a]	--	22	NA	--
Min. detected (µg/kg)	16	19	23	21	30	NA	140
Max. detected (µg/kg)	66	47	150	21	290	NA	140
Max. detected location	SH-14	SH-21	OB-01	OB-19	HI-02	NA	RF-03
Polychlorinated biphenyls (PCBs)							
Number of samples	27	25	17	3	6	0	3
Total PCBs							
% Detected	3.7	0	0	0	16.7	NA	0
Min. nondetect (mg/kg OC)	0.036	0.035	0.085	0.084	0.27	NA	0.59
Max. nondetect (mg/kg OC)	0.12	2.5	0.44	9.1	0.61	NA	1.4
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.62	--	--	--	2.5	NA	--
Max. detected (mg/kg OC)	0.62	--	--	--	2.5	NA	--
Max. detected location	SH-01	--	--	--	HI-06	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Chlorinated pesticides							
Number of samples	26	25	17	3	6	0	3
4,4’-DDD							
% Detected	33.3	48.0	11.8	33.3	33.3	NA	33.3
Min. nondetect (µg/kg)	0.14	0.13	0.14	0.14	0.13	NA	0.13
Max. nondetect (µg/kg)	0.27	0.26	0.15	0.15	0.15	NA	0.14
Mean (µg/kg)	0.55[a]	0.59[a]	--	--	--	NA	--
Median (µg/kg)	0.17[a]	0.22[a]	--	--	--	NA	--
Min. detected (µg/kg)	0.34	0.14	0.31	1.0	0.19	NA	0.15
Max. detected (µg/kg)	2.9	3.6	0.36	1.0	0.33	NA	0.15
Max. detected location	SH-04 /SH-14	SH-21	OB-02	OB-18	HI-07	NA	RF-02
4,4’-DDE							
% Detected	40.7	36.0	11.8	66.7	16.7	NA	0
Min. nondetect (µg/kg)	0.13	0.13	0.13	0.14	0.13	NA	0.13
Max. nondetect (µg/kg)	0.23	0.23	0.16	0.14	0.14	NA	0.14
Mean (µg/kg)	0.57[a]	0.38[a]	--	--	--	NA	--
Median (µg/kg)	0.16[a]	0.17[a]	--	--	--	NA	--
Min. detected (µg/kg)	0.24	0.14	0.63	0.30	1.2	NA	--
Max. detected (µg/kg)	4.1	1.5	3.1	0.33	1.2	NA	--
Max. detected location	SH-14	SH-01	OB-02	OB-19	HI-07	NA	--
4,4’-DDT							
% Detected	18.5	36.0	35.3	33.3	33.3	NA	33.3
Min. nondetect (µg/kg)	0.14	0.14	0.14	0.15	0.15	NA	0.14
Max. nondetect (µg/kg)	0.23	0.26	0.17	0.15	0.15	NA	0.15
Mean (µg/kg)	--	0.74[a]	0.80[a]	--	--	NA	--
Median (µg/kg)	--	0.19[a]	0.061[a]	--	--	NA	--
Min. detected (µg/kg)	0.24	0.27	0.31	1.6	0.96	NA	0.57
Max. detected (µg/kg)	4.8	5.8	5.6	1.6	4.5	NA	0.57
Max. detected location	SH-12	SH-14	OB-04	OB-19	HI-04	NA	RF-01
Aldrin							
% Detected	14.8	28.0	0	0	0	NA	0
Min. nondetect (µg/kg)	0.10	0.10	0.21	0.22	0.20	NA	0.20
Max. nondetect (µg/kg)	0.23	0.22	0.25	0.23	0.22	NA	0.22
Mean (µg/kg)	--	0.99[a]	--	--	--	NA	--
Median (µg/kg)	--	0.058[a]	--	--	--	NA	--
Min. detected (µg/kg)	0.63	0.15	--	--	--	NA	--
Max. detected (µg/kg)	4.8	19	--	--	--	NA	--
Max. detected location	SH-14	SH-08	--	--	--	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
alpha-Chlordane							
% Detected	14.8	36.0	0	33.3	0	NA	66.7
Min. nondetect (µg/kg)	0.11	0.11	0.13	0.13	0.12	NA	0.13
Max. nondetect (µg/kg)	0.23	0.18	0.98	0.14	0.13	NA	0.13
Mean (µg/kg)	--	0.27 [a]	--	--	--	NA	--
Median (µg/kg)	--	0.048 [a]	--	--	--	NA	--
Min. detected (µg/kg)	0.14	0.13	--	0.28	--	NA	0.19
Max. detected (µg/kg)	4.3	2.5	--	0.28	--	NA	0.49
Max. detected location	SH-14	SH-21	--	OB-19	--	NA	RF-01
Dieldrin							
% Detected	18.5	12.0	5.9	0	16.7	NA	0
Min. nondetect (µg/kg)	0.11	0.11	0.11	0.12	0.11	NA	0.11
Max. nondetect (µg/kg)	0.23	0.18	0.13	0.12	0.12	NA	0.12
Mean (µg/kg)	--	--	--	--	--	NA	--
Median (µg/kg)	--	--	--	--	--	NA	--
Min. detected (µg/kg)	0.12	0.18	0.12	--	0.13	NA	--
Max. detected (µg/kg)	3.4	1.9	0.12	--	0.13	NA	--
Max. detected location	SH-14	SH-28	OB-07	--	HI-07	NA	--
gamma-BHC							
% Detected	33.3	28.0	11.8	33.3	16.7	NA	0
Min. nondetect (µg/kg)	0.074	0.074	0.073	0.078	0.071	NA	0.072
Max. nondetect (µg/kg)	0.12	0.12	0.089	0.079	0.077	NA	0.077
Mean (µg/kg)	0.42 [a]	0.24 [a]	--	--	--	NA	--
Median (µg/kg)	0.082 [a]	0.035 [a]	--	--	--	NA	--
Min. detected (µg/kg)	0.29	0.17	0.11	0.34	0.25	NA	--
Max. detected (µg/kg)	4.4	2.8	1.4	0.34	0.25	NA	--
Max. detected location	SH-14	SH-20	OB-05	OB-17	HI-07	NA	--
Heptachlor							
% Detected	14.8	4.0	5.9	0	0	NA	0
Min. nondetect (µg/kg)	0.13	0.13	0.44	0.46	0.42	NA	0.43
Max. nondetect (µg/kg)	0.13	0.12	0.47	0.47	0.46	NA	0.46
Mean (µg/kg)	--	--	--	--	--	NA	--
Median (µg/kg)	--	--	--	--	--	NA	--
Min. detected (µg/kg)	0.19	16	1.1	--	--	NA	--
Max. detected (µg/kg)	5.6	16	1.1	--	--	NA	--
Max. detected location	SH-14	SH-08	OB-09	--	--	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Petroleum Hydrocarbons							
Number of samples	5	2	3	0	0	0	3
Motor oil							
% Detected	20.0	50.0	0	NA	NA	NA	0
Min. nondetect (mg/kg)	160	150	150	NA	NA	NA	130
Max. nondetect (mg/kg)	360	150	270	NA	NA	NA	150
Mean (mg/kg)	--	--	--	NA	NA	NA	--
Median (mg/kg)	--	--	--	NA	NA	NA	--
Min. detected (mg/kg)	220		--	NA	NA	NA	--
Max. detected (mg/kg)	220	270	--	NA	NA	NA	--
Max. detected location	SH-05	SH-02	--	NA	NA	NA	--
Dioxin/Furans							
Number of samples	27	9	17	5	6	0	3
Total Dioxin (TEQ)							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (ng/kg)	--	--	--	--	--	NA	--
Max. nondetect (ng/kg)	--	--	--	--	--	NA	--
Mean (ng/kg)	42.8	198	32.1	97.8	5.42	NA	0.482
Median (ng/kg)	35.5	16.2	33.0	82.0	2.95	NA	0.508
Min. detected (ng/kg)	1.00	2.68	4.44	52.4	1.77	NA	0.245
Max. detected (ng/kg)	175	902	54.4	180	13.0	NA	0.692
Max. detected location	SH-03	SH-10	OB-12	OB-06	HI-03	NA	RF-01
Resin Acids							
Number of samples	13	11	9	3	2	0	3
Total resin acids							
% Detected	100	90.9	100	100	100	NA	66.7
Min. nondetect (µg/kg)	--	98	--	--	--	NA	98
Max. nondetect (µg/kg)	--	98	--	--	--	NA	98
Mean (µg/kg)	3,300	17,000 [a]	1,500	4,500	--	NA	--
Median (µg/kg)	2,500	2,100	1,200	3,000	--	NA	--
Min. detected (µg/kg)	270	130	740	1,700	1,400	NA	120
Max. detected (µg/kg)	9,000	68,000	3,200	8,900	2,800	NA	730
Max. detected location	SH-24	SH-21	OB-02	OB-19	HI-04	NA	RF-02

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
12-Chlorodehydroabietic acid							
% Detected	7.7	0	0	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	98	NA	98
Max. nondetect (µg/kg)	300	480	300	300	98	NA	99
Mean (µg/kg)	--	--	--	--	--	NA	--
Median (µg/kg)	--	--	--	--	--	NA	--
Min. detected (µg/kg)	130	--	--	--	--	NA	--
Max. detected (µg/kg)	130	--	--	--	--	NA	--
Max. detected location	SH-19	--	--	--	--	NA	--
Abietic acid							
% Detected	92.3	81.8	77.8	100	0	NA	33.3
Min. nondetect (µg/kg)	96	98	99	--	98	NA	98
Max. nondetect (µg/kg)	96	98	100	--	98	NA	99
Mean (µg/kg)	1,200 [a]	9,000 [a]	350 [a]	2,700	--	NA	--
Median (µg/kg)	840	1,600	200 [a]	1,700	--	NA	--
Min. detected (µg/kg)	120	230	120	610	--	NA	730
Max. detected (µg/kg)	3,300	38,000	920	5,900	--	NA	730
Max. detected location	SH-22	SH-21	OB-17	OB-19	--	NA	RF-02
Dehydroabietic acid							
% Detected	84.6	90.9	55.6	100	0	NA	0
Min. nondetect (µg/kg)	96	98	99	--	98	NA	98
Max. nondetect (µg/kg)	98	98	100	--	98	NA	99
Mean (µg/kg)	1,400 [a]	4,300 [a]	260 [a]	1,200	--	NA	--
Median (µg/kg)	840[a]	530	170 [a]	1,000	--	NA	--
Min. detected (µg/kg)	120	110	170	530	--	NA	--
Max. detected (µg/kg)	4,200	22,000	710	2,000	--	NA	--
Max. detected location	SH-24	SH-21	OB-17	OB-19	--	NA	--
Isopimaric acid							
% Detected	53.8	63.6	11.1	100	0	NA	0
Min. nondetect (µg/kg)	96	97	99	--	98	NA	98
Max. nondetect (µg/kg)	300	99	300	--	98	NA	99
Mean (µg/kg)	190[a]	1,200[a]	--	420	--	NA	--
Median (µg/kg)	120[a]	230[a]	--	290	--	NA	--
Min. detected (µg/kg)	100	120	170	110	--	NA	--
Max. detected (µg/kg)	540	3,700	170	870	--	NA	--
Max. detected location	SH-22	SH-21	OB-17	OB-19	--	NA	--

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
Linolenic acid							
% Detected	46.2	18.2	11.1	0	100	NA	0
Min. nondetect (µg/kg)	96	97	97	97	--	NA	98
Max. nondetect (µg/kg)	300	300	300	300	--	NA	99
Mean (µg/kg)	160[a]	--	--	--	--	NA	--
Median (µg/kg)	150[a]	--	--	--	--	NA	--
Min. detected (µg/kg)	160	150	100	--		NA	--
Max. detected (µg/kg)	290	1,000	100	--	290	NA	--
Max. detected location	SH-30	SH-21	OB-02	--	HI-04	NA	--
Neoabietic acid							
% Detected	0	18.2	0	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	98	NA	98
Max. nondetect (µg/kg)	300	480	300	300	98	NA	99
Mean (µg/kg)	--	--	--	--	--	NA	--
Median (µg/kg)	--	--	--	--	--	NA	--
Min. detected (µg/kg)	--	280	--	--	--	NA	--
Max. detected (µg/kg)	--	550	--	--	--	NA	--
Max. detected location	--	SH-18	--	--	--	NA	--
Oleic acid							
% Detected	92.3	36.4	77.8	0	100	NA	33.3
Min. nondetect (µg/kg)	300	97	97	97	--	NA	98
Max. nondetect (µg/kg)	300	480	300	300	--	NA	98
Mean (µg/kg)	320[a]	150[a]	980 [a]	--	--	NA	--
Median (µg/kg)	300 U	74[a]	880 [a]	--	--	NA	--
Min. detected (µg/kg)	150	140	610	--	1,300	NA	120
Max. detected (µg/kg)	650	820	1,800	--	2,500	NA	120
Max. detected location	SH-24	SH-21	OB-02	--	HI-04	NA	RF-01
Palustric acid							
% Detected	0	27.3	0	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	98	NA	98
Max. nondetect (µg/kg)	300	290	300	300	98	NA	99
Mean (µg/kg)	--	330[a]	--	--	--	NA	--
Median (µg/kg)	--	250[a]	--	--	--	NA	--
Min. detected (µg/kg)	--	530	--	--	--	NA	--
Max. detected (µg/kg)	--	920	--	--	--	NA	--
Max. detected location	--	SH-18	--	--	--	NA	--

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

	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
Parameter Group	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Pimaric acid							
% Detected	0	9.1	11.1	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	98	NA	98
Max. nondetect (µg/kg)	300	480	300	300	98	NA	99
Mean (µg/kg)	--	--	--	--	--	NA	--
Median (µg/kg)	--	--	--	--	--	NA	--
Min. detected (µg/kg)	--	220	99	--	--	NA	--
Max. detected (µg/kg)	--	220	99	--	--	NA	--
Max. detected location	--	SH-21	OB-17	--	--	NA	--
Retene							
% Detected	69.2	81.8	0	100	NA	NA	0
Min. nondetect (µg/kg)	8.7	20	19	--	NA	NA	20
Max. nondetect (µg/kg)	20	20	20	--	NA	NA	20
Mean (µg/kg)	160[a]	4,100[a]	--	210	NA	NA	--
Median (µg/kg)	28[a]	50[a]	--	160	NA	NA	--
Min. detected (µg/kg)	10	15	--	48	NA	NA	--
Max. detected (µg/kg)	900	21,000	--	430	NA	NA	--
Max. detected location	SH-19	SH-21	--	OB-17	NA	NA	--
Sandaracopimaric acid							
% Detected	7.7	27.3	0	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	110	NA	98
Max. nondetect (µg/kg)	300	480	300	300	160	NA	99
Mean (µg/kg)	--	310[a]	--	--	--	NA	--
Median (µg/kg)	--	170[a]	--	--	--	NA	--
Min. detected (µg/kg)	1,300	570	--	--	--	NA	--
Max. detected (µg/kg)	1,300	1,300	--	--	--	NA	--
Max. detected location	SH-21	SH-21	--	--	--	NA	--

NA	Not analyzed.
OC	organic carbon (normalized)
mg/kg	milligram per kilogram
µg/kg	microgram per kilogram
--	Not able to calculate.

[a] Values are estimated using regression on ordered statistics (ROS).

Diesel- and gasoline-range petroleum hydrocarbons and guaiacols (associated with wood waste) are not included on this table because there were no detections of those chemicals.

Table 4-2. Reference sediment associated with Oakland Bay study sediment samples.

Sample	Total Fines (percent)	Organic Carbon (percent)	Associated Reference Sediment Sample			
			Amphipod	Larval	Polychaete	Microtox [a]
REF-1	81.2	0.639	NA	NA	NA	NA
REF-2	51.5	0.589	NA	NA	NA	NA
REF-3	13.1	0.273	NA	NA	NA	NA
SH-01	27.8	1.59	Ref-3	Ref-3	Ref-2 [b]	Control [c]
SH-02	59.7	2.46	Ref-2	Ref-3 [b]	Ref-2	Control [c]
SH-03	66.2	3.8	Ref-2	Ref-3 [b]	Ref-2	Control [c]
SH-04	76	4.13	Ref-1	Ref-3 [b]	Ref-1	Control[c]
SH-05	29	3.2	Ref-3	Ref-3	Ref-3	Control [c]
SH-07	34.2	1.59	Ref-2	Ref-2	Ref-2	Control [c]
SH-09	32.4	2.17	Ref-2	Ref-3 [b]	Ref-2	Control [c]
SH-10	15	2.03	Ref-3	Ref-3	Ref-2 [b]	Ref-3
SH-11	63.4	2.32	Ref-2	Ref-2	Ref-2	Control [c]
SH-12	57.6	4.79	Ref-2	Ref-2	Ref-2	Control [c]
SH-13	65.3	11	Ref-2	Ref-2	Ref-2	Control [c]
SH-14	51.7	3.1	Ref-2	Ref-3 [b]	Ref-2	Control [c]
SH-15	4.6	0.542	Ref-3	Ref-3	Ref-3	Ref-3
SH-16	2.2	0.511	Ref-3	Ref-3	Ref-3	Ref-3
SH-18	85	4.79	Ref-1	Ref-1	Ref-1	Ref-1
SH-19	67.3	4.44	Ref-1 [d]	Ref-3 [b]	Ref-1 [d]	Control [c]
SH-20	77.2	5.15	Ref-1	Ref-3 [b]	Ref-1	Ref-1
SH-21	76.2	5.59	Ref-1	Ref-3 [b]	Ref-1	Ref-1
SH-22	36.8	5.77	Ref-2	Ref-3 [b]	Ref-2	Ref-3
SH-23	64.8	3.33	Ref-2	Ref-3 [b]	Ref-2	Control [c]
SH-24	42	4.97	Ref-2	Ref-3 [b]	Ref-2	Control [c]
SH-25	49.6	2.6	Ref-2	Ref-2	Ref-2	Control [c]
SH-26	12.8	1.92	Ref-3	Ref-3	Ref-3	Control [c]
SH-27	21.6	1.38	Ref-3	Ref-3	Ref-3	Ref-3
SH-28	24.1	1.24	Ref-3	Ref-3	Ref-2 [b]	Control [c]
SH-29	4.1	0.594	Ref-3	Ref-3	Ref-3	Ref-3
SH-30	31.2	1.99	Ref-3	Ref-3	Ref-3	Ref-3
OB-01	11.9	0.878	Ref-3	Ref-3	Ref-2[b]	Ref-3
OB-02	31.1	1.4	Ref-3	Ref-3	Ref-2 [b]	Control[c]
OB-03	69.5	2.79	Ref-2	Ref- 3 [b]	Ref-1	Control [c]

Table 4-2 (continued). Reference sediment associated with Oakland Bay study sediment samples.

Sample	Total Fines (percent)	Organic Carbon (percent)	Associated Reference Sediment Sample			
			Amphipod	Larval	Polychaete	Microtox [a]
OB-04	42.6	3.45	Ref-2	Ref-2	Ref-2	Control [c]
OB-05	71.6	2.35	Ref-1	Ref-1	Ref-1	Ref-1
OB-06	96.9	4.68	Ref-1	Ref-1	Ref-1	Ref-1
OB-07	16.9	0.995	Ref-3	Ref-3	Ref-3	Ref-3
OB-08	87.4	1.36	Ref-1	Ref-1	Ref-1	Ref-1
OB-09	87.8	2.69	Ref-1	Ref-1	Ref-1	Ref-1
OB-10	84.2	2.62	Ref-1	Ref-1	Ref-1	Ref-1
OB-11	44.1	2.32	Ref-2	Ref-2	Ref-2	Ref-1
OB-12	91.6	2.26	Ref-1	Ref-1	Ref-1	Ref-1
OB-13	66.2	3.53	Ref-2	Ref-2	Ref-2	Control [c]
OB-14	24.5	1.71	Ref-3	Ref-3	Ref-2 [b]	Control [c]
OB-17	21.2	2.39	Ref-3	Ref-3	Ref-2 [b]	Control [c]
OB-18	82.6	2.86	Ref-1	Ref-1	Ref-1	Ref-1
OB-19	92	2.6	Ref-1	Ref-1	Ref-1	Ref-1
HI-02	6	0.571	Ref-3	Ref-3	Ref-2 [b]	Ref-3
HI-03	13.7	1.45	Ref-3	Ref-3	Ref-3	Ref-3
HI-04	4.3	0.625	Ref-3	Ref-3	Ref-2 [b]	Ref-3
HI-05	6.9	0.799	Ref-3	Ref-3	Ref-3	Control [c]
HI-06	16.7	2.43	Ref-3	Ref-3	Ref-2 [b]	Ref-3
HI-07	6.8	0.68	Ref-3	Ref-3	Ref-2 [b]	Control [c]

[a] Microtox analyses were performed before grain size analysis conducted by the laboratory; therefore, selection of appropriate reference sediment was based on field wet sieving results.

[b] The appropriate reference sample failed toxicity test criteria. As an alternative, the test sediment was compared to a reference sample passing toxicity test criteria with the next closest matching grain size in the test batch.

[c] Microtox analyses were performed with only one reference sample per analytical batch. In this case, the reference sample failed toxicity test criteria. As an alternate, the test sediment was compared to the laboratory control sample, as no other reference sample was available for comparison in the test batch.

[d] The total fines for this sample were near the breakpoint between using reference REF-1 or REF-2. The test sediment was compared to the second closest match of grain size (within 1 percent difference of the closest matching grain size) because the test failed criteria when using the alternate reference sample.

The reference sediment samples were collected with high, medium, and low fines content. Sediment samples were then compared to the reference sediment with comparable fines content. Ecology's Sediment Sampling and Analysis Plan Appendix (Ecology 2008) directs that test sediment percent fines should be within 20 percent of the selected reference sediment. Percent fines of the reference sediments were 81.2 percent (REF-1), 51.5 percent (REF-2), and 13.1 percent (REF-3); adding he 20 percent measure resulted in overlapping comparison ranges of 0 – 33.1 percent, 31.5 – 71.5 percent, and 61.2 – 100 percent fines. In order to select one reference sample for comparison for each sample location, the midway point between each measured grain size range was selected as the 'cutoff' point. Test sediments with less than 32.3 percent fines were compared to reference sediment REF-3, those with percent fines between 32.3 and 66.35 percent were compared to reference sediment REF-2, and test sediments with greater than 66.35 percent fines were compared to reference sediment REF-1. In those cases where test sediment percent fines were very close to the reference sample cutoff points (SH-03, SH-09, SH-12, SH-19, OB-13), the percent fines of the sample was compared to the reference sample closer in grain size. Percent fines for each sample, and the reference used for comparison in each bioassay test, are shown in Table 4–2.

The reference sample with the closest matching percent fines content was *not* selected for comparison to the surface sediment samples when:

- The closest matching reference sample failed toxicity test criteria – two or three of the reference samples were included with each test batch, and as an alternative, the test sediment was compared to a reference sample passing toxicity test criteria with the next closest matching grain size in the test batch. (refer to Section 4.5.2).
- Microtox analyses were performed with only one reference sample per analytical batch – if the reference sample failed toxicity test criteria, the test sediment was compared to the laboratory control sample, as no other reference sample was available for comparison in the test batch.

Table 4-3 includes the list of organisms used in each of the toxicity tests, and each primary test endpoint. A summary of SQS and CSL results for all toxicity tests is presented in Table 4-4. As shown in Table 4-4, 25 of the 50 samples met SQS and CSL criteria, nine samples exceeded SQS criteria, and 16 samples exceeded CSL criteria, based on all four toxicity tests. The acute larval test had the most failures (14 CSL and seven SQS), the chronic polychaete test had seven SQS failures, and the acute amphipod and chronic Microtox test each had one SQS failure. The bioassay laboratory report is provided in Appendix H.

4.4 Radiology

Sediment cores OB-15, OB-16, and SH-17 were subjected to radioisotope analysis to determine historical patterns of sedimentation and accumulation in Oakland Bay and Shelton Harbor.

Table 4-3. SMS biological effect criteria and applicability.

Biological Test	Sediment Quality Standards	Cleanup Screening Levels	Species	Primary Endpoint(s)
Amphipod Mortality	The test sediment has a higher (statistically significantly, t-test, P≤0.05) mean mortality than the reference sediment, and the test sediment mean mortality is more than 25% on an absolute basis.	The test sediment has a significantly higher (t-test, P≤0.05) mean mortality than the reference sediment, and the test sediment mean mortality is more than 30% greater, on an absolute basis, than the reference sediment mean mortality.	*Ampelisca abdita* *Eohaustorius estuaries*	Mortality
Larval Development	The test sediment has a mean survivorship of normal larvae that is significantly less (t-test, P≤0.1) than the mean normal survivorship in the reference sediment, and the mean normal survivorship in the test sediment is less than 85% of the mean normal survivorship in the reference sediment.	The test sediment has a mean survivorship of normal larvae that is significantly less (t-test, P≤0.1) than the mean normal survivorship in the reference sediment, and the mean normal survivorship in the test sediment is less than 70% of the mean normal survivorship in the reference sediment.	*Mytilus* sp.	Abnormality Mortality
Juvenile Polychaete Growth	The mean individual growth rate of polychaetes in the test sediment is less than 70% of the mean individual growth rate of the polychaetes in the reference sediment, and the test sediment mean individual growth rate is statistically different (t-test, P≤0.05) from the reference sediment mean individual growth rate.	The mean individual growth rate of polychaetes in the test sediment is less than 50% of the mean individual growth rate of the polychaetes in the reference sediment, and the test sediment mean individual growth rate is statistically different (t-test, P≤0.05) from the reference sediment mean individual growth rate.	*Neanthes arenaceodentata*	Biomass
Microtox (porewater) bioluminescence	The mean light output of the highest concentration of the test sediment is less than 80 % of the mean light output of the reference sediment, and the two means are statistically different (t-test, P≤0.05).	Not Applicable	*Vibrio fischeri*	Luminescence

Table 4-4. Summary of Oakland Bay study toxicity testing results compared to SMS criteria.

	Amphipod (*A. abdita* or *E. estuarius*)	Larval (*Mytilus* sp.)	Polychaete (*N. arenaceodentata*)	Microtox		
				Sample Mean of Initial Light Output (percent)		Overall Station Status
Station	Absolute Mortality (percent)	Normal Survivorship Relative to Reference	MIG Relative to Reference	5 min	15 min	SQS or CSL [b]
SH-01	10	0.94	0.739 [a]	100	96	Pass
SH-02	6	**0.49** [a]	0.926	101	98	**CSL**
SH-03	14	**0.49** [a]	0.831	96	92	**CSL**
SH-04	9	**0.63** [a]	0.928	100	97	**CSL**
SH-05	15	**0.26**	0.704	106	100	**CSL**
SH-07	5	**0.67**	0.880	95	86	**CSL**
SH-09	12	1.01 [a]	0.901	101	98	Pass
SH-10	7	1.07	0.744 [a]	103	98	Pass
SH-11	7	1.16	1.020	100	96	Pass
SH-12	11	1.01	1.014	95	86	Pass
SH-13	8	1.12	**0.639**	94	87	**SQS**
SH-14	18	**0.80**[a]	0.833	103	103	**SQS**
SH-15	3	1.22	0.928	101	97	Pass
SH-16	2	1.12	0.690	101	93	Pass
SH-18	10	0.85	0.755	100	95	Pass
SH-19	15	**0.58** [a]	**0.654**	102	97	**CSL**
SH-20	10	1.04 [a]	0.920	102	94	Pass
SH-21	14	**0.53** [a]	0.714	102	94	**CSL**
SH-22	10	**0.63** [a]	**0.643**	110	104	**CSL**
SH-23	18	0.86 [a]	0.727	103	101	Pass
SH-24	18	**0.47** [a]	0.785	98	95	**CSL**
SH-25	21	1.08	0.914	103	100	Pass
SH-26	13	**0.83**	0.631	100	94	**SQS**
SH-27	8	1.25	0.780	100	96	Pass
SH-28	6	0.99	**0.691** [a]	101	97	**SQS**
SH-29	4	1.29	0.814	106	106	Pass
SH-30	9	0.91	1.002	106	100	Pass
OB-01	11	1.11	0.817 [a]	98	93	Pass
OB-02	21	1.05	0.771[a]	102	98	Pass
OB-03	**29**	0.99 [a]	0.588	103	101	**SQS**
OB-04	5	**0.76**	1.167	97	90	**SQS**
OB-05	9	**0.74**	**0.595**	**43**	**35**	**CSL**
OB-06	14	**0.68**	0.724	104	95	**CSL**
OB-07	14	1.04	0.734	104	101	Pass

Table 4-4 (continued). Summary of Oakland Bay study toxicity testing results compared to SMS criteria.

	Amphipod (*A. abdita* or *E. estuarius*)	Larval (*Mytilus* sp.)	Polychaete (*N. arenaceodentata*)	Microtox		
				Sample Mean of Initial Light Output (percent)		Overall Station Status
Station	Absolute Mortality (percent)	Normal Survivorship Relative to Reference	MIG Relative to Reference	5 min	15 min	SQS or CSL[b]
OB-08	8	0.93	0.748	101	92	Pass
OB-09	10	**0.79**	0.820	99	95	**SQS**
OB-10	6	**0.54**	0.919	103	97	**CSL**
OB-11	11	1.17	0.785	94	89	Pass
OB-12	21	**0.84**	0.771	101	92	**SQS**
OB-13	10	**0.69**	**0.681**	92	86	**CSL**
OB-14	10	**0.65**	0.782 [a]	95	90	**CSL**
OB-17	10	0.96	1.008 [a]	96	91	Pass
OB-18	12	**0.56**	0.770	104	96	**CSL**
OB-19	8	**0.55**	0.917	100	95	**CSL**
HI-02	4	1.11	**0.625** [a]	107	111	**SQS**
HI-03	17	1.04	1.028	108	105	Pass
HI-04	2	1.06	1.062 [a]	115	121	Pass
HI-05	1	1.32	0.837	99	94	Pass
HI-06	7	0.97	0.822 [a]	104	109	Pass
HI-07	2	1.26	0.941 [a]	97	96	Pass

[a] Bioassays must be run with reference sediments that are well-matched to the test sediments for grain size. In this case, the appropriate reference sample failed toxicity test criteria. As an alternative, the test sediment was compared to a reference sample passing toxicity test criteria with the next closest matching grain size in the test batch. In the case of the larval test, two of the three reference sediments for Batch 1 did not meet the test criteria; therefore, all bioassays from Batch 1 of the larval test were compared with Reference 3.

[b] SQS or CSL station exceedance. A station with two or more SQS exceedances is assigned a CSL exceedance under the Sediment Management Standards (WAC 173-204-520(1)(d) and (3)(d)).

Bold indicates SQS failure.

Bold underline indicates CSL failure.

MIG	mean individual growth.
min	minute.

Lead-210 measurements are routinely employed to date recent marine sediments. The technique works by examining change in the relative presence of lead-210 with depth. Lead-210 is created when lead at the earth's surface is bombarded by radiation from space (cosmogenic). Lead-210 in the sediment ceases to be created once it is buried during the sedimentation process. Lead-210, created when the sediment was exposed on the surface to cosmogenic radiation, decays at a known rate. By measuring the amount of lead-210 throughout the sediment cores, it can be determined how long it has been since that particular sediment was buried. The sedimentation rate can be estimated by examining the trend in reduction of lead-210 with depth below the seabed.

Deposition of cesium-137 began in 1946 as a result of thermonuclear activities worldwide. The deepest trace of its presence in a core defines a timeframe benchmark to compare with lead-210 findings. An estimated sediment deposition rate is assumed and core sections on either side of the estimated 1946 surface are analyzed. When results of the deeper sample indicate no cesium-137 and the next shallower core section selection indicates cesium presence, then the 1946 benchmark depth is bracketed. Lead-210 analysis is performed first to help identify the appropriate depth; however, selecting the optimal core sections can be difficult. Both elements are primarily associated with fine-grained sediments, not with sand and gravels.

All of the cores exhibited expected trends of lead-210, decreasing with depth (Figure 4-4); however, not all presented clear transition breakpoints useful for interpretation.

Core OB-15 indicated a clearly defined lead-210 starting layer and gradual increase in radioactivity moving upward; OB-16 presented a less clear trend. It required three cesium-137 core section samples in the OB-15 core and five core section samples in the OB-16 core to adequately define the 1946 benchmark.

Due to the sand and gravel content of core SH-17, lead-210 was difficult to interpret. Based on the poor preliminary lead-210 results, it was decided to not analyze core SH-17 for cesium-137, but to evaluate the other cores in more detail. The presence of extensive gravel throughout the SH-17 core appeared to result from Goldsborough Creek deposits associated with channelization of the creek by man. This alternative timeframe benchmark provided a non-radiological means of dating the sediment.

Analytical results for all the radioisotope cores are presented in Appendix I.

4.5 Data Validation

A QA1 data review was performed for all chemical, toxicity, and radiology data collected for this project. A QA1 data review evaluates field collection and handling, completeness, data presentation, detection limits, and the acceptability of test results for method blanks, certified reference materials, analytical replicates, matrix spikes, and surrogate recoveries. A QA1 review for bioassay data covers similar field and reporting elements and evaluates the acceptability of test results for positive controls, negative controls, reference sediment, replicates, and

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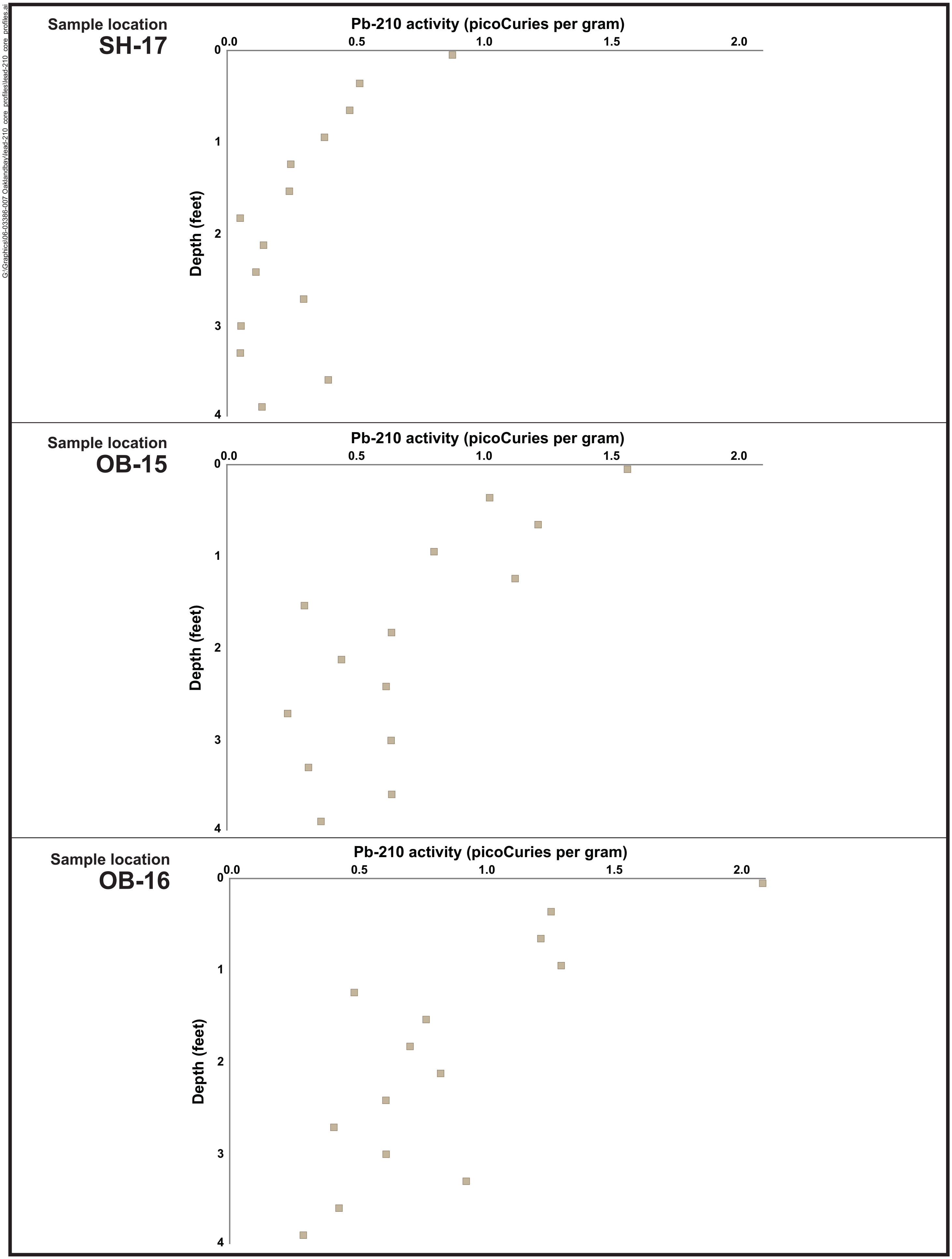

Figure 4-4. Lead-210 core profiles in Shelton Harbor and Oakland Bay.

experimental conditions (e.g. temperature, salinity, pH, dissolved oxygen). The QA1 data reviews were performed based on data quality objectives outlined in the project *Sampling and Analysis Plan* (Herrera 2008); completed QA1 memoranda are provided in Appendix J. In general, chemistry data met project criteria and are considered acceptable for use. Approximately 450 of 15,000 chemistry results (3 percent) were qualified due to holding time, precision, or accuracy criteria failures; no data were rejected. A summary of data quality issues encountered is provided for chemical, toxicity, and radiology data in the following sections.

4.5.1 Chemical Data Validation

All chemistry data are considered acceptable for use as intended, with the minor qualifications described below:

- Low matrix spike recoveries – several total sulfide results were qualified as estimated or estimated detection limit values due to low matrix spike recoveries.
- Laboratory duplicate criteria exceedances – the total sulfide result for sample OB-12-WC-12 and total mercury result for sample SH-21-WS-00 were qualified as estimated.
- Low matrix spike recovery values and laboratory duplicate criteria exceedances – all PCB and pesticide compounds for sample SH-21-WS-00 were qualified as estimated or estimated detection limit.
- Holding time exceedances – several samples analyzed for pesticides and PCBs were qualified as estimated or estimated detection limit.
- Primary and confirmation column criteria exceedances – several PCB and pesticide compound results were qualified as estimated.
- Method blank criteria exceedance – bis(2ethylhexyl) phthalate (BEHP) results were qualified as estimated or nondetected.
- Internal standard criteria exceedance – several SVOCs for sample SH-21-WS-12 were qualified as estimated detection limit values.
- High surrogate recoveries – several resin acid compound results for sample SH-12-WC-12 were qualified as estimated.
- Low laboratory control sample recoveries – several neoabietic acid results were qualified as estimated or estimated detection limit values.

4.5.2 Toxicity Data Validation

One or more reference sediment samples (REF-1, REF-2, REF-3) failed toxicity analysis criteria for the larval development, juvenile polychaete growth test, or Microtox test. In these cases, test sediment was compared to the next closest passing reference sediment sample with respect to grain size, or to the control sample in the case of the Microtox test. No other data quality issues were identified for the toxicity analyses and no data were qualified.

4.5.2.1 *Bioassay Water Quality Results*

Water quality test condition protocols and summary of daily measurements are presented in Table 4–5. The temperature, salinity, dissolved oxygen, and pH were all within control limits and acceptable ranges throughout the tests, with minor exceptions for the amphipod mortality, larval development, and juvenile polychaete growth test, as described below:

- Temperature dropped below control limits for the juvenile polychaete growth bioassays, and rose above the control limits for the amphipod mortality bioassay and for one batch for the juvenile polychaete growth bioassay

- Salinity rose above control limits for one of the amphipod mortality bioassays and the juvenile polychaete growth bioassays

- Dissolved oxygen dropped below control limits for the juvenile polychaete growth bioassays.

These water quality deviations are not believed to have had significant effects on the test results.

The water quality measurements (interstitial and overlying) for ammonia and sulfides are presented in Table 4–6. The total ammonia and sulfide concentrations were all below levels of potential concern in bioassay test results (DMMP 2002; DMMP 2004), with the exception described below:

- The initial interstitial sulfide concentration for sample OB-10-SS-00 (18 milligram per liter [mg/L]) exceeded the level of potential concern (3.4 mg/L) for the juvenile polychaete bioassay; however, sample OB-10-SS-00 passed the toxicity test criteria.

- Based on the water quality measurements, there do not appear to be any adverse effects on test organisms due to laboratory test conditions.

4.5.2.2 *Negative Control and Reference Sediment Performance Results*

Reference sediments are used in comparison with test sediments for interpreting bioassay results. Three reference locations from Carr Inlet were sampled for comparison to the test sediments collected from Oakland Bay. Carr Inlet is recognized as a suitable reference area for the collection of sediments for interpreting bioassay results.

Table 4-5. Water quality test results compared to test control limits, Oakland Bay study.

Test (test species)	Control Limits/Test Results	Temperature	Salinity	Dissolved Oxygen	pH [a]
Amphipod Mortality (*A. abdita*)	Control Limits	20 ± 1°C	28 ± 2 ppt	≥5.0 mg/L	7.3 – 8.3
	Test Results [b]	19.4 to 23.8 °C	27 – 35 ppt	6.6-8.7 mg/L	7.6 – 8.8
Amphipod Mortality (*E. estuarius*)	Control Limits	15 ± 1°C	28 ± 2 ppt	≥5.0 mg/L	7.3 – 8.3
	Test Results [b]	15.0 to 16.9 °C	28 – 30 ppt	6.4-9.7 mg/L	7.4 – 8.5
Larval Development (*Mytilus* sp.)	Control Limits	16 ± 1°C	28 ± 1 ppt	≥4.8 mg/L	7.3 – 8.3
	Batch 1 Test Results [b]	15.1 to 16.5 °C	28 ppt	5.2 – 9.7 mg/L	7.3 – 8.0
	Batch 2 Test Results [b]	15.2 to 16.6 °C	27 – 28 ppt	6.0 – 8.8 mg/L	7.5 – 8.2
Juvenile Polychaete Growth (*N. arenaceodentata*)	Control Limits	20 ± 1°C	28 ± 2 ppt	≥6.0 mg/L	7.0 – 9.0
	Batch 1 Test Results [b]	16.9 to 20.7 °C	27 – 32 ppt	2.9 – 10.7 mg/L	7.1 – 8.8
	Batch 2 Test Results [b]	18.4 – 23.0 °C	28 – 32 ppt	3.6 – 14.2 mg/L	7.6 – 8.9
Microtox Bioluminescence (*V. fischeri*)	NA [c]	15 °C[d]	20 ± 2 ppt [e]	50 – 100% saturation [f]	7.9 – 8.2

[a] pH is required for water quality monitoring, but does not have explicit control limits.

[b] Water quality test results are for reference and test sediment parameters only; does not include negative control results.

[c] Water quality is not monitored, but the 100 percent porewater extract of the sediment sample is adjusted for temperature, pH, dissolved oxygen, and salinity.

[d] Temperature is maintained at 15°C in an incubator during testing.

[e] Same as interstitial.

[f] Continuous aeration is required by the method, so DO concentration is not a cause of concern.

°C	degrees Celcius
mg/L	milligrams per liter
ppt	parts per thousand
NA	not applicable

Source: Ecology (2003)

Table 4-6. Water quality measurements of total ammonia and sulfides, Oakland Bay study.

Test (test species)	Batch	Ammonia (interstitial) (mg/L)	Ammonia (overlying) (mg/L)	Sulfides (interstitial) (mg/L)	Sulfides (overlying) (mg/L)
Amphipod Mortality (*A. abdita*)	1	<0.5– 8.34	<0.5– 2.32	0 – 0.241	0 – 0.150
Amphipod Mortality (*E. estuarius*)	1	<0.5– 8.79	<0.5– 1.89	0.019 – 0.797	0 – 0.032
Larval Development (*Mytilus* sp.)	1	NA	<0.5 - 0.541	NA	0 – 0.570
	2	NA	<0.5	NA	0.002 – 0.124
Juvenile Polychaete Growth (*N. arenaceodentata*)	1	<0.5 – 5.03	<0.5 – 0.745	0.006 – 0.392	0 – 0.026
	2	<0.5 – 8.92	<0.5 – 2.88	0 – 18	0 – 0.055
Microtox Bioluminescence (*V. fischeri*)	1-14	NA	2.7 – 45.6	NA	NA

mg/L	milligrams per liter
NA	not applicable

The performance results of the negative control and reference sediments for each bioassay are presented in Table 4-7. The negative control performance standards were met for all four bioassays; therefore, test results for amphipod mortality, larval development, juvenile polychaete, and Microtox should be considered valid for the purpose of SMS confirmatory biological tests. Reference sediments did not meet certain performance criteria, as described below:

- Reference samples REF-01-SS-00 and REF-02-SS-00 did not meet the performance criteria in Batch 1 for the larval development bioassay.
- Reference sample REF-03-SS-00 did not meet the performance criteria in Batch 1 for the juvenile polychaete growth bioassay.
- Reference sample REF-02-SS-00 did not meet the performance criteria in any of the six batches analyzed for Microtox.
- Reference sample REF-03-SS-00 did not meet the performance criteria in one of the five batches analyzed for Microtox.

Table 4-7. Performance standards and results for negative controls and reference sediments, Oakland Bay study.

Test (test species)	Performance Standard	Negative Control		Performance Standard	Reference Sediment	
		Batch 1	Batch 2		Batch 1	Batch 2
Amphipod Mortality (*A. abdita)*	$M_C \leq 10\%$	9%	NA	$M_R < 25\%$	REF-01: 15% REF-02: 13%	NA
Amphipod Mortality (*E. estuarius)*	$M_C \leq 10\%$	1%	NA	$M_R < 25\%$	REF-02: 15% REF-03: 13%	NA
Larval Development (*Mytilus* sp.)	$N_C \div I \geq 0.70$	0.84	1.03	$N_R \div N_C \geq 65\%$	**REF-01: 51.2%** **REF-02: 45.0%** REF-03: 70.2%	REF-01: 85.6% REF-02: 65.7% REF-03: 78.6%
Juvenile Polychaete Growth (*N. arenaceodentata*)	$M_C \leq 10\%$ $MIG_C > 0.38$ [a]	0.0% 0.563	0.0% 0.414	MIG_R/ MIG_C <80%	REF-01: 91.7% REF-02: 96.3% **REF-03: 65.9%**	REF-01: 136% REF-02: 106% REF-03: 95.2%
Microtox Bioluminescence (*V. fischeri*)	$M_C > 80\%$[b]	83-102%[c]	NA	$M_R > 80\%$[b]	REF-01: 92-102% [c] **REF-02: 49-65% [c]** **REF-03: 66-100% [c]**	NA

Bold font indicates performance criteria not met.

[a] Target MIGc is 0.72 mg/individual/day; the test is considered as failed if the Control MIG is less than 0.38 mg/individual/day.

[b] Percent mean light output of final control or reference relative to initial control or reference.

[c] The bioassays were performed in several batches; reference sediment results are provided as a range.

M	mean mortality
N	mean normal development survival in seawater control
NA	not applicable
I	initial count
MIG	mean individual growth rate (mg/individual/day)

Subscripts: R = reference; C = negative control

Because of these reference sample failures, all samples analyzed in Batch 1 for the larval development bioassay were compared to reference sample REF-03-SS-00; all samples analyzed in Batch 1 for the juvenile polychaete growth bioassay were compared to reference samples REF-01-SS-00 or REF-02-SS-00 (Michelsen and Shaw 1996). For Microtox bioassays, samples were compared to control samples if reference samples failed performance criteria.

4.5.2.3 *Positive Control Results*

Bioassay reference toxicant test results are provided in Table 4-8. The median lethal concentration (LC50) values for all the bioassays fell within the acceptable range of mean +/- two standard deviations for historical reference toxicant data generated by the laboratory. The reference toxicant results indicate the test organisms appeared to be sufficiently sensitive for demonstrating a toxic response and sufficiently robust for laboratory testing. The reference control charts, with both current and running means and standard deviation, are provided in Appendix H.

Table 4-8. Bioassay reference toxicant results, Oakland Bay study.

Test (test species)	Reference Toxicant	Endpoint	Test Batch	LC50	Laboratory Historical Range (mean +/- 2SD)
Amphipod Mortality (*A. abdita*)	Cadmium chloride	96-hour survival	1	0.32 mg/L	0.135 – 1.14 mg/L
Amphipod Mortality (*E. estuaries*)	Cadmium chloride	96-hour survival	1	13.4 mg/L	4.0 – 12.2 mg/L
Larval Development (*Mytilus* sp.)	Copper chloride	normality	1	7.4 µg/L	3.4 – 18.7 µg/L
			2	8.3 µg/L	3.5 – 18.0 µg/L
Juvenile Polychaete Growth (*N. arenaceodentata*)	Cadmium chloride	96-hour survival	1	6.8 mg/L	2.4 – 16.9 mg/L
			2	8.0 mg/L	
Microtox Bioluminescence (*V. fischeri*)	Phenol	luminescence	1-14	23.8 – 59.0 mg/L	20.7 – 68.7 mg/L

mg/L	milligrams per liter
µg/L	microgram per liter
LC50	median lethal concentration
SD	standard deviation

4.5.3 Radiology Data Validation

No data quality issues were identified for the radiological analyses and no data were qualified.

5.0 Evaluation of Study Area Conditions

This section presents an evaluation of study area conditions based on data presented in Section 4, including descriptions of general geomorphologic processes (provided in Appendix E). Comparisons to other historical information are provided in Section 7.

The geomorphic assessment was based on information associated with area-wide data gathering (i.e., geologic process evaluation and geophysics) and location-specific sources (i.e., sediment core lithology and radioisotope dating). Location-specific data can define conditions related to current and historical activities conducted at that position in the bay, but can also be used to support development of a model that may indicate conditions reflecting broader bay-wide processes. In this study, geophysical survey results were derived from a series of transects, determined in the field based on site conditions and the features to be interpreted by the specific survey type. Later, sediment cores were collected and interpreted for lithology at a single point in space.

The results of both techniques were compared and data from the core samples evaluated within the context of the overall site model (discussed further in Section 5.2.3). This may have resulted in conflicts on a small scale (e.g., where sediment layer thickness associated with wood, defined by the geophysical survey, did not exactly correspond to visible wood volume at a particular core location). To obtain more precise measures of wood waste characteristics both laterally and vertically over small spaces, a more detailed data gathering study would be required in the area of concern. The results of this bay-wide study provide adequate information to focus further efforts.

5.1 Bathymetry

Oakland Bay is an embayment at the southwestern end of Puget Sound. Like the rest of Puget Sound, Oakland Bay was glaciated and carved out during the last ice age. Central Oakland Bay and Hammersley Inlet are most probably the remnants of a subglacial channel formed during glacial retreat, but still reflecting the original shape; the bay has been filled with sediment eroded from the surrounding landscape. A majority of sediment input to the study area comes from creeks located in Shelton Harbor, in Chapman Cove, at Bayshore Point, and at the head of the bay (Goldsborough Creek represents two thirds of the total sediment input to Oakland Bay). Creek deltas are shallow areas influenced by drainage from upland areas and small local waves, and are dominated by flood discharges with high sand content. The heavy sand is deposited near the creek mouths, while muddy sediment (silt and clay) remains suspended and is transported into deeper water.

Oakland Bay water depths vary from 15 feet (4.6 meters) to 80 feet (26.2 meters) below MLLW during high tide. A deep hole covering 1,000 feet by 500 feet (300 meters by 150 meters) varies in depth from 45 to 80 feet (14 to 24 meters) at the transition of Oakland Bay to Hammersley Inlet (Figure 4-1). A relict channel, maintained by modern tidal flow and up to 50 feet

(15 meters) deep, stretches north from this hole, past the eastern boundary of Shelton Harbor and along the western edge of lower Oakland Bay. Shallow tidal flats up to 10 feet (3 meters) deep at high tide dominate most of the southeast shoreline of Oakland Bay, Chapman Cove, and the head of the bay. Much of northern and western Shelton Harbor is dominated by shallow areas resulting from creek deltas that can vary up to 15 feet (4.6 meters) deep, depending on tide conditions. The remainder of Shelton Harbor is deeper and has been dredged to a depth of approximately 10 to 15 feet (3 to 4.5 meters) below MLLW.

The relict channel is no longer apparent in Chapman Cove and north of Bayshore Point, as it has been filled with sediment. Eroded sediment from the surrounding landscape is also reflective of glaciation, being comprised of glacial till (varying from silt to gravel and cobble), outwash sand, and glacial lacustrine silt and clay. Hardpoint bedrock outcroppings are common at the interface between Hammersley Inlet and Oakland Bay. This is evident in the subbottom profiles generated by the geophysical survey (Appendix E, Figure 4). The hardpoints at the interface of Oakland Bay and Hammersley Inlet effectively constrict tidal flow through a narrow and deep subglacial channel.

Past work describing geologic and hydrographic conditions in Oakland Bay indicates a low energy, tidally influenced estuary that occupies a drowned drainage network. The extreme tide range in Oakland Bay ensures strong near-bed flood currents, little ebb tide flushing (mostly surficial water), and a high retention rate of local sediment inputs (Albertson 2004). Fresh water that enters the bay from creeks is less dense than marine salt water. During tidal cycles, fresh and marine waters mix; however, the fresh water tends not to mix deeply. As a consequence, the fine grain and colloidal sediment fractions (a small mass fraction of the total sediment load) entrained in the fresh water move out of the bay near the surface. This means that although there are local high velocity tidal currents at the junction between Oakland Bay and Hammersley Inlet, most sediment that originates in Oakland Bay remains there.

The dense seawater delivered to the bay likely flows along the deep channel bottom, as evidenced by the orientation of the marine bedforms at its south end (Appendix E, Bedform 1 in Figure 4). The steeper slopes on the ‘downstream’ side of the rippled bedform feature indicate water flow into Oakland Bay from Hammersley Inlet at depth. Shallow-water marine bedforms (Bedform 2, Appendix E, Figure 4) oriented toward Hammersley Inlet also confirm that less dense, less saline flow is occurring out of Oakland Bay at shallower depths (Albertson 2004). No other bedforms were found in the study area.

5.2 Sediment and Wood Waste Distribution

Vashon recessional outwash and proglacial stratified sand and gravel with variable amounts of silt were deposited as glacial ice receded across the area. These deposits extend northeast of Shelton along the western shoreline, continuing to the north end of Oakland Bay as the ground surface. Beneath this layer, glacial till was deposited by glacier ice along Shelton Harbor to the north and south; it is composed of a highly compacted mixture of clay, silt, sand, and gravel. Below the till, Vashon advance outwash consists of layers of sand and gravel and lacustrine clay, silt, and sand deposited in front of the advancing glacier. The advance outwash is commonly exposed where topography is steep and the overlying till has been removed by erosion. It is found along the northwest shoreline of the bay, on the shoreline and slopes to the north of Chapman Cove, and on either side of the shoreline where the bay becomes Hammersley Inlet. Pre-Vashon gravel deposits have been cemented and are well compacted. They are found on steep slopes between the till and recessional deposits, particularly to the north and south of the fill material in Shelton Harbor and along the eastern slopes of Oakland Bay. Typically, the unconsolidated deposits are underlain by volcanic basalt bedrock in this area.

5.2.1 Sediment Lithology

With core penetration of 12 feet (3.6 meters) or less, none of the glacial till or glaciofluvial units discussed above were found in the sediments (although till may have been encountered at SH-25, causing core refusal – low tide observations indicated a rock shelf extending from the shore). Eroded material from the glacial units was found in sediment cores collected throughout the study area, including alluvial deposits of sand and gravel found overlying fine-grained marine deposits consisting of silty clay and clayey silt.

Twenty-seven cores were collected from Shelton Harbor, with the following sediment grain size characteristics:

Grain Size	Number of Samples
Primarily coarse	6
Transition from coarse to fine from top to bottom	2
Transition from fine to coarse from top to bottom	4
Primarily fine	15

Cores with coarse sediment throughout were collected from the Goldsborough and Shelton Creek deltas. Before human development, the creeks feeding Shelton Harbor were not channelized, instead depositing most of their sand and gravel much further to the west as they meandered slowly through a complex network of channels on the delta (now the downtown area). Since being channelized, they now deliver sand and gravel rapidly to the middle of the harbor.

The two cores exhibiting a coarse-to-fine transition from top to bottom were found in the north and east portions of the harbor directly impacted by the creeks. Upward grain-size coarsening in the cores indicates recent delivery of sand and gravel overlying a heterogeneous sub-layer with some fine grain material present.

All samples collected from the south side of the harbor were composed either entirely of fine-grain material or material grading from fine to coarse downward. Before human development, significant amounts of sand and gravel were likely deposited along the southern shore of Shelton Harbor from erosion of adjacent bluffs. With human development, the base of the bluff has been protected with fill and rock revetments and creek discharge limited to the north side of the harbor. The loss of generally coarse sediment input, along with fine material re-suspended from nearby dredging operations, has resulted in the upward fining pattern observed in these cores.

Nineteen cores were collected from Oakland Bay, with the following sediment grain size characteristics:

Grain Size	Number of Samples
Primarily coarse	2
Transition from coarse to fine from top to bottom	0
Transition from fine to coarse from top to bottom	1
Primarily fine	16

One core with coarse sediment throughout was collected east of Bayshore Point from a deep hole maintained by intermittent intense flow. This area collects large amounts of shells from the surrounding area at the north end of the bay. The shells are trapped because they are transported to the area via bedload (transport that occurs near the bed), but cannot escape out of the hole. Fine-grain material is not deposited because the currents in the area are too strong to allow deposition. The other coarse sediment core was collected from the shoreline just north of the marina, adjacent to historical bulk fuel facilities. This sample was collected from the steep side slope of the deep trough seen in the bathymetric map (Figure 4-1).

The one core with a fine-to-coarse transition from top to bottom was located at the mouth of the creeks at the head of the bay. The fine-to-coarse transition here is similar to the creek deltas in Shelton Harbor and likely has a similar origin (i.e., confinement of streamflow from development).

Most cores collected from Oakland Bay consisted of fine-grain sediments throughout, indicating long-term deposition, distant from energetic sources (creeks) where coarse-grain sediment deposits first.

Six cores were collected from Hammersley Inlet, with the following sediment grain size characteristics:

Grain Size	Number of Samples
Primarily coarse	3
Transition from coarse to fine from top to bottom	1
Transition from fine to coarse from top to bottom	1
Primarily fine	1

Coarse grain material was noted in five of the samples, located both along the sides of the deep trough and in the middle of the channel. The one core exhibiting primarily fine-grained sediment was collected from the depositional flat located south of Eagle Point.

The distribution of sediment provides clues to the direction of sediment transport in the study area. Sediment varies from coarse to fine along the direction of transport. Coarse material is found at the creek deltas that surround Oakland Bay and in Hammersley Inlet. While there are pockets of sediment accumulation in Hammersley Inlet and the smaller embayments, for the most part, sediment varies from coarse to fine moving from the source to final destination in deeper portions of the bay. Thus, the broad distribution of predominantly fine material across Oakland Bay indicates that this area is far from sediment sources and represents the final place of deposition within the study area.

Review of sediment core logs across most of Oakland Bay indicates a general pattern of coarser clayey silt found in the top 2 feet (0.6 meter), transitioning to finer silty clay below (the 2-foot transition depth varies up to a foot (0.3 meter) in either direction at a few locations). Those cores that do not exhibit this pattern were collected adjacent to shorelines or alluvial fans. Hammersley Inlet and Shelton Harbor sampling stations did not follow this pattern, reflecting areas of relatively high hydraulic energy (i.e., alluvial fans and scoured beds). Much of the harbor exhibited clayey silt starting at depths ranging from 1 to 3 feet (0.3 to 1.0 meter), overlain by courser material (usually containing sand).

5.2.2 Sediment Accumulation Rates

Three sediment cores from Shelton Harbor and Oakland Bay (SH-17, OB-15, and OB-16) were sampled for the presence and concentrations of lead-210 and cesium-137 to estimate sediment accumulation rates. Detailed analysis provided in Appendix E). SH-17 was collected on the Goldsborough Creek delta, OB-15 was collected in the middle of Oakland Bay, and OB-16 was collected near the Johns Creek delta, south of Bayshore Point (Figures 3-2 and 3-3).

Core SH-17, collected on the edge of the Goldsborough Creek delta, included large quantities of sand and gravel associated with relatively recent sediment input from the creek. As a result, the core did not contain a significant amount of lead-210 typically associated with older, fine-grained sediments (see Section 4.1.2.3). The lack of fine-grained sediments at this location made precise determination of sediment age impossible. However, the presence of gravel in the core provided independent geomorphic evidence of an average accumulation rate of approximately 0.39 in/year (1 cm/year) at this location (based on the assumption that the deepest gravel, at 4 feet [1.2 meter], was deposited after the onset of major development, around 1900).

Core OB-15, collected from the middle of Oakland Bay indicated a sediment accumulation rate of between 0.11 and 0.20 inch/year (0.27 and 0.51 cm/year) based on cesium-137 presence at 6.8 in (17 cm) and absence at 12.8 in (32 cm). The lead-210 results independently support this conclusion because background levels of lead-210 are achieved at 18.8 in (47 cm) depth.

Core OB-16, collected from the north end of the main portion of Oakland Bay provided a less clear-cut picture of sediment accumulation. The lead-210 results suggest an accumulation rate of approximately 0.10 in/year (0.25 cm/year). The cesium-137 measurements constrain the accumulation rate to greater than 0.26 in/year (0.66 cm/year). While there is a possibility that the discrepancy between the lead-210 and cesium-137 measurements could be explained by disturbance of the seabed between 1946 and 1985 or so (e.g., by shellfish management activities), it is also possible that the low lead-210 concentrations in older sediments were too close to the detection limit for an accurate accumulation rate determination. Even though these results represent a disturbed site, they are generally consistent with the results seen at the other core locations.

The three sediment cores collected for radioisotope analyses represent the fringe of substantial creek sediment input to Shelton Harbor (SH-17), relatively undisturbed central Oakland Bay (OB-15), and an area of transition between disturbed and undisturbed portions of Oakland Bay (OB-16). Together, the radioisotope analytical results and core lithologies indicate that sediment accumulation rates vary across the Oakland Bay system, between 0.10 and 0.20 inches/year (0.25 and 0.51 cm/year) in central Oakland Bay, and possibly exceeding 0.40 inches/year (1 cm/year) in areas of preferential sediment accumulation (i.e., near creek deltas).

A geomorphic analysis of the Oakland Bay system performed before radiological core testing estimated sediment accumulation rates based on sediment input analysis and modeling, with an average accumulation rate determined as 0.23 in/year (0.57 cm/year) across the study area (Appendix E). This is close to the measured range of 0.10 and 0.20 in/year (0.25 to 0.51 cm/year) based on the radioisotope analysis. The rate of fine grain sediment accumulation within central Oakland Bay does not appear to reflect only inputs from adjacent creeks and shorelines.

The only other sources of sediment in the system can be attributed primarily to the creeks in Shelton Harbor and, to a lesser extent, Hammersley Inlet. Since Shelton Harbor exceeds the average accumulation rate estimated from the sediment input analysis (i.e., approximately 0.4 in/year [1 cm/year]) and areas far from sediment sources achieve somewhere between 50 and 90 percent of the anticipated accumulation rate, it appears that sediment accumulates in Oakland Bay. These conclusions are consistent with other qualitative evidence of high near-bed water flow and associated sediment transport artifacts (e.g., bedforms oriented into the bay and hydrographic modeling discussed in Appendix E).

Geophysical survey data identified a broadly distributed, recently deposited surface layer generally extending 1 to 3 feet (0.3 to 1 meter) deep. The transition between recent and older sediment layers was discernable in core logs, characterized by less dense clayey silt on top of denser silty clay in non-alluvial areas. This less dense surface layer coincides with increased human activities that have resulted in higher sediment delivery rates through increased upland erosion, channelization of Shelton Harbor creeks, and the introduction of wood waste (channelization of the creeks has resulted in increased hydraulic forces that transport fine grain material further into the bay). The addition of wood waste also has contributed to lower overall sediment density. It is possible that this transition also could be corroborated using radiological data; however, analysis of many more core sections would have been required, and a higher clay content throughout.

5.2.3 Wood Waste Distribution

Evidence of wood was found in 80 percent of all sample locations and was observed at all depths sampled. Percentage of wood presence visually estimated from cores is shown in Figures 5-1 and 5-2.

The geophysical survey data represented in Figures 4-2 and 4-3 depict the thickness of recent deposition indicated by acoustic tomography. The map is based on a network of survey transects, with no modification to fit data to core log observations at individual sampling stations. Evidence of wood waste found in cores penetrating recent deposits across the study area supports the strength of the geophysical evidence. Because uncompacted wood does not transmit sound well, sediments containing wood produce a distinct signature characteristic of low acoustic reflectivity. In this study, the slow sound speed associated with wood-containing sediments helped to enhance the contrast with older, more consolidated wood-free sediments beneath, where the sound speed was much faster. The relatively higher wood content found in recent sediment deposits is an artifact of increased wood processing that began in the late 1880s.

Shelton Harbor geophysical survey results presented in Figure 4-3 proved to be of marginal use. Approximately one-half of the harbor could not be reliably mapped, due to the presence of significant gravel in the creek deltas – significant amounts of coarse-grain material and dynamic sedimentation characteristics obscure the definition of the interface with the pre-development layer. In those areas with finer grain sediment within the harbor, high wood content also caused acoustic signal attenuation. In these cases, layer surfaces could not be mapped. Additionally, it was not possible to map beneath the present-day log rafting area in the southeast part of the harbor because of limited access. Sample SH-24 was obtained close to the existing log rafts and contained 50 percent bark at the surface. A core sample was not collected in this location due to refusal of the sampling equipment. As a result of these factors, the significant accumulation of wood in the south harbor area shown on Figure 4-3 could neither be accurately mapped or quantified.

Figures 5-3 and 5-4 provide comparisons of geophysical results to core log information (cores with wood at the bottom did not reach the bottom of the wood layer, due to refusal). Wood was identified in recent deposits where wood was intensively handled (i.e., in deeper portions of Shelton Harbor, at rafting locations around the perimeter of Oakland Bay) and adjacent to the trough along the north shoreline of lower Oakland Bay where finer grain sediment has tended to accumulate – compare area-wide color shades (recent depositional layer thickness) to circle sizes (average visible wood thickness at core locations). Note that the relatively thick deposit extending along the north shoreline of lower Oakland Bay is well represented by OB-02 and OB-17 and that the deposit boundaries are defined by HI-7, OB-03, -05, and -15.

No wood was found in cores collected from the center of Oakland Bay (OB-03, -05, -09, and -15) where wood rafts were not regularly stored (a review of available historical information identified a log raft lease area at the mouth of Chapman Cove [Herrera 2008a] and various aerial photographs indicated rafting along the shoreline of lower Oakland Bay and across Shelton Harbor [Appendix E]).

Wood waste was found in two distinct modes across the study area: broadly distributed, low concentrations of wood (less than 20 percent) mixed with sediment, and thick, highly concentrated wood layers. Figures 5-1 and 5-2 indicate the vertical distribution of wood content at each sampling station based on visual estimates (provided in Appendix F). Table 5-1 provides a summary of the general presence of wood waste across the study area by depth.

Table 5-1. Summary of Oakland Bay study core samples containing visible wood.

	Shelton Harbor		Oakland Bay		Hammersley Inlet	
Core Section (feet)	Wood Present	No. of Samples	Wood Present	No. of Samples	Wood Present	No. of Samples
0-1	76%	22 of 29	35%	6 of 17	43%	3 of 7
1-2	65%	17 of 26	53%	9 of 17	50%	3 of 6
2-3	60%	15 of 25	41%	7 of 17	0%	0 of 6
3-4	45%	10 of 22	19%	3 of 16	17%	1 of 6
4-5	25%	5 of 20	21%	3 of 14	0%	0 of 6
5-6	29%	5 of 17	50%	2 of 4	0%	0 of 4
6-7	27%	3 of 11	20%	1 of 5	0%	0 of 1

Observed wood was 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. Approximately half of the time, only one form of wood was found in a core.

Wood waste distribution was most prevalent as bark, found at 70 percent of all sampling stations. Fourteen locations exhibited bark at greater than 5 percent wood content and 23 locations exhibited less than 5 percent wood. Bark was found in 65 percent of Shelton Harbor stations, 88 percent of Oakland Bay stations, and 43 percent of Hammersley Inlet stations. The primary source of bark is likely from log rafts that have historically been stored across much of Shelton Harbor and the perimeter of Oakland Bay, including multi-acre tracts west of Chapman Cove and west of Munson Point (Herrera 2008a). The majority of this material was found in Shelton Harbor, where logs were delivered to the water by train (railway log dump), and by tug boats. Concentrated log handling activities along the shoreline where logs have been transferred in and out of storage have resulted in the largest accumulations of bark.

Wood waste was found as chips at 26 percent of the sampling stations. Two locations exhibited chips at greater than 5 percent wood content and 12 locations exhibited chips at less than 5 percent wood content. Chips were found in 45 percent of Shelton Harbor stations, no Oakland Bay stations, and one Hammersley Inlet station. The primary source of chips is likely from wood processing operations.

Wood waste was found as fibers at 23 percent of the sampling stations. Three locations exhibited fibers at greater than 5 percent wood content and nine locations exhibited fibers at less than 5 percent wood content. Fibers were found in 45 percent of Shelton Harbor stations, two

Figure 5-1.
Visible percent wood content in Oakland Bay and Hammersley Inlet sediment samples at 1-foot intervals.

Legend

Total percent wood content

○	Sample location - no wood found at any depth
□	No wood at given depth
🟨	0.5 to 5%
🟫	5.1 to 10%
🟫	10.1 to 20%
🟫	20.1 to 50%
■	> 50%

Collected sample depth (1-foot intervals)

- 0-1 foot
- 1-2 feet
- 2-3 feet
- 3-4 feet
- 4-5 feet
- 5-6 feet
- 6-7 feet
- 7-8 feet
- 8-9 feet
- 9-10 feet

Notes: Each station shown to the depth sampled; top box represents sample station location.

No core collected at HI-05. Wood content reflects that found in surface grab sample.

N

0 1,050 2,100 4,200 Feet

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Aerial: USDA, 2009

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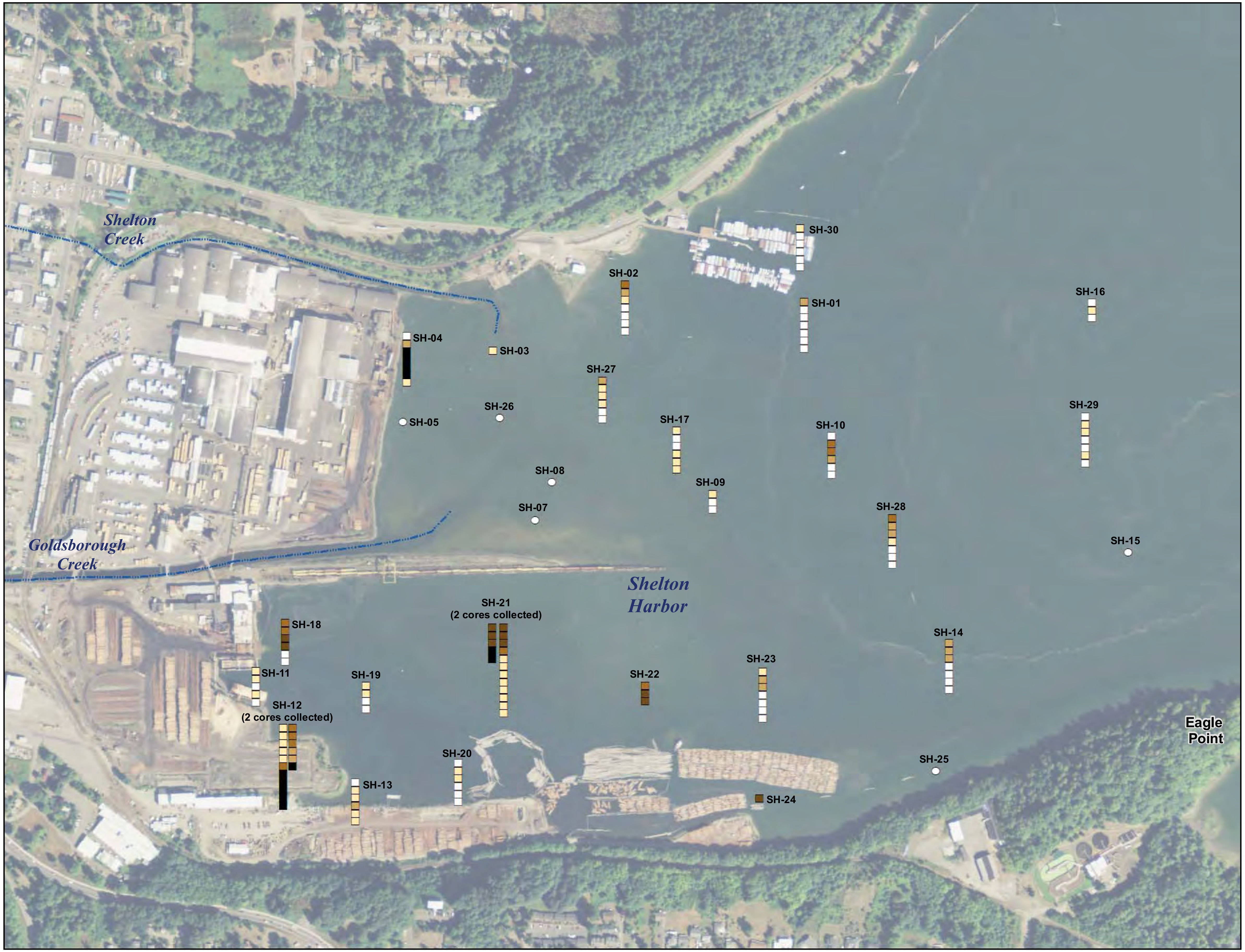

Figure 5-2.
Visible percent wood content in Shelton Harbor sediment samples at 1-foot intervals.

Legend

Total percent wood content

○ Sample location - no wood found at any depth

☐ No wood at given depth

■ 0.5 to 5%

■ 5.1 to 10%

■ 10.1 to 20%

■ 20.1 to 50%

■ > 50%

Collected sample depth (1-foot intervals)

☐ 0-1 foot
☐ 1-2 feet
☐ 2-3 feet
☐ 3-4 feet
☐ 4-5 feet
☐ 5-6 feet
☐ 6-7 feet
☐ 7-8 feet
☐ 8-9 feet
☐ 9-10 feet

Notes: Each station shown to the depth sampled; top box represents sample station location.

No surface grab or core collected at SH-06, due to high cobble content (not shown on map).

No cores collected at SH-03, SH-24, and SH-25; wood content reflects that found in surface grab sample.

Wood content based on visual inspection, provided in Appendix F.

N

0 250 500 1,000
Feet

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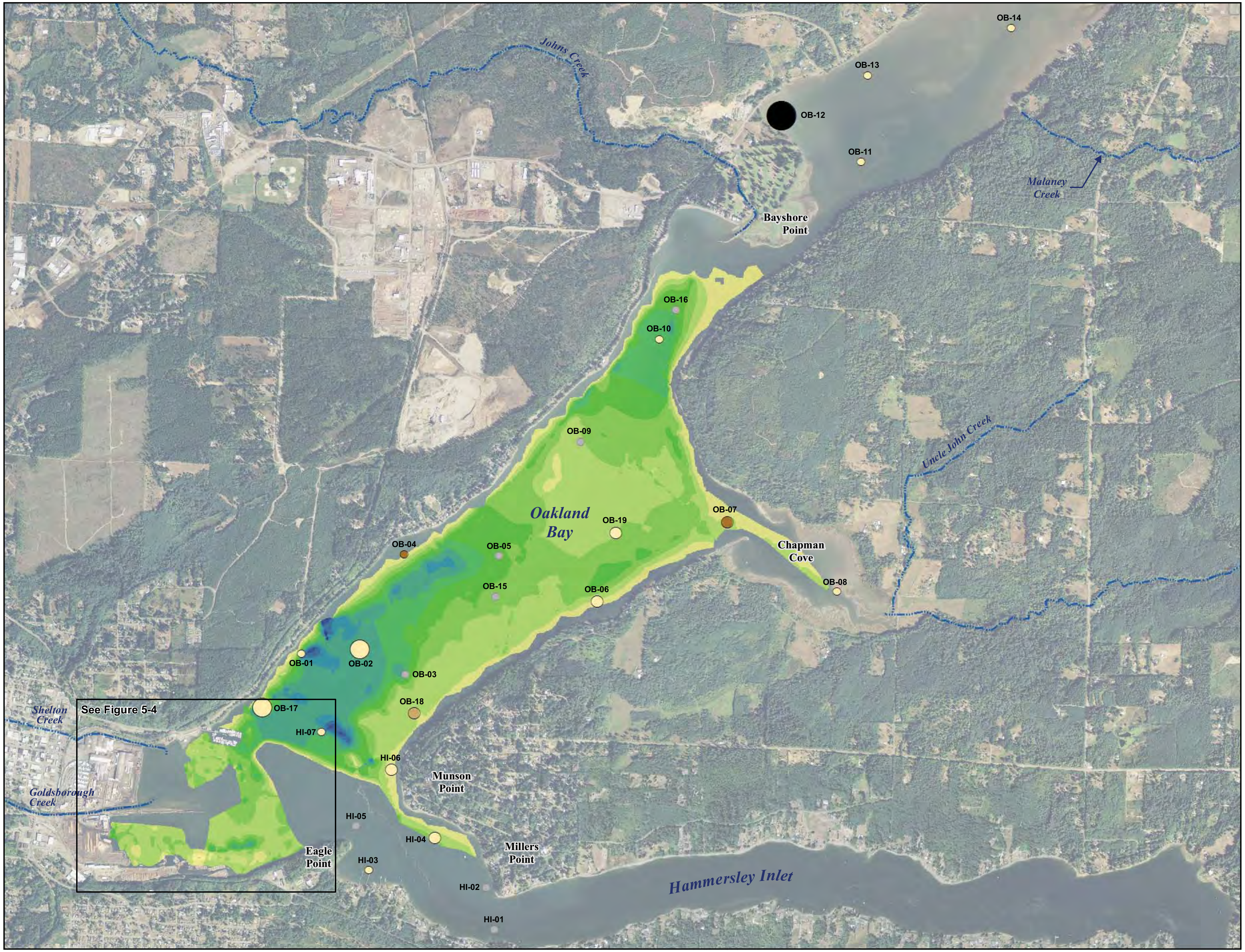

Figure 5-3.
Total percent visible wood content compared to recent depositional layer thickness in Oakland Bay and Hammersley Inlet.

Legend

Total percent visible wood content at sample location

- ● No wood found at any depth
- ● 0.5 to 5%
- ● 5.1 to 10%
- ● 10.1 to 20%
- ● 20.1 to 50%
- ● > 50%

Visible wood thickness at sample location (feet)

- ○ 1 foot
- ○ 2 to 4 feet
- ○ 5 to 7 feet
- ○ > 7 feet

Recent depositional layer thickness (feet)

- 🟨 0 to 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

N

0 1,050 2,100 4,200 Feet

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Aerial: USDA, 2009

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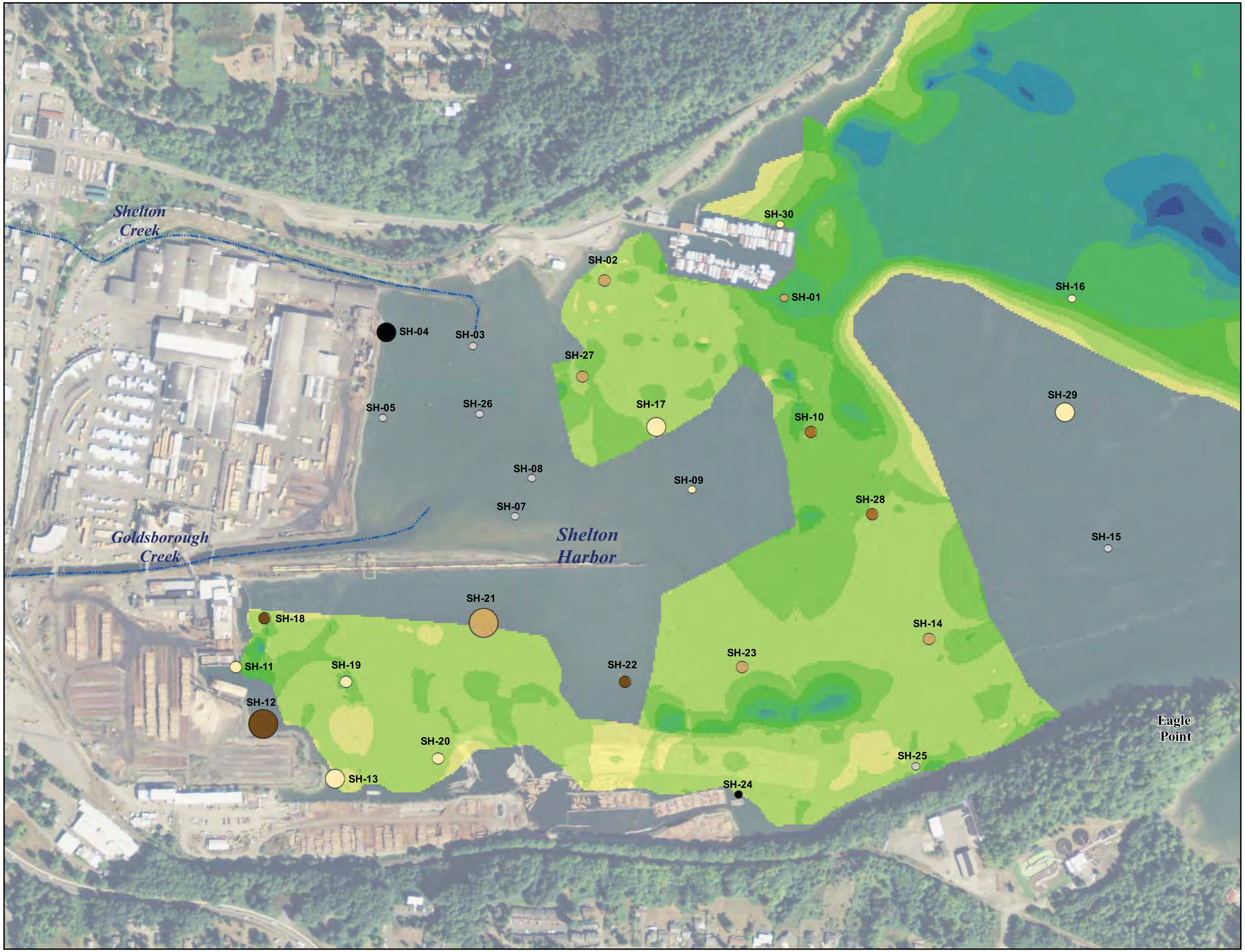
Figure 5-4.
Total percent visible wood content compared to recent depositional layer thickness in Shelton Harbor.



Legend

Total percent visible wood content sample location
- ● No wood found at any depth
- ● 0.5 to 5%
- ● 5.1 to 10%
- ● 10.1 to 20%
- ● 20.1 to 50%
- ● > 50%

Visible wood thickness at sample location (feet)
- ○ 1 foot
- ○ 2 to 4 feet
- ○ 5 to 7 feet
- ○ > 7 feet

Recent depositional layer thickness (feet)
- 🟨 0 to 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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Oakland Bay stations, and one Hammersley Inlet station. The primary source of fibers is likely from wood processing operations. Fibers were likely discharged as part of the sulfite liquor waste associated with historical paper production and as waste from fiberboard processing; their presence appears to be restricted mostly to the south side of Shelton Harbor and, to a limited extent, to the north side of the harbor and along the southern shore of lower Oakland Bay.

Wood waste was found as sawdust at 6 percent of the sampling stations. All three locations with sawdust exhibited significant accumulations (greater than 50 percent). The primary source of sawdust is likely from wood sawing operations located at the west end of Shelton Harbor and at the head of Oakland Bay, likely associated with an historical sawmill, either located on the adjacent shore (not found in the historical review) or across the bay (discussed in Section 5.2.3.2).

Wood was not found in four portions of the study area:

- Shelton Harbor within the alluvial fans of Goldsborough and Shelton Creeks, due to high sand and gravel content (SH-03, -05, -07, -08, -26)
- Shelton Harbor and Hammersley Inlet along the Eagle Point shoreline, extending out in to the channel, due to the presence of bedrock and gravel content (SH-15, -25; HI-01, -02, -05)
- Central Oakland Bay, likely due to a general lack of sources (OB-03, -05, -09, -15, -16)
- Bathymetric low spot at the Head of the Bay where shell fragments dominate (OB-11)

5.2.3.1 *Area-wide Distribution*

Wood waste was found at 80 percent of all sample locations across the study area. Except for localized areas of high accumulation, wood was found at less than 20 percent by volume across the uppermost layer of sediment, associated with the onset of European settlement and development. This post-development layer was defined by sediment lithology (i.e., core logs) and the geophysical survey (acoustic tomography) that identified a distinct layer of recent sediment accumulation ranging from 1 to 8 feet (0.3 to 2.5 meter) in depth across the study area (Figures 5-1 and 5-2).

When averaged throughout the bay, the thickness of visible wood waste deposits (Table 5-2) was nearly identical to the average 3 foot (1 meter) post-development layer thickness estimated from the geophysical surveys (this does not account for localized areas of higher wood waste accumulation, discussed below). The recent depositional layer contained approximately 5 percent wood waste by volume when averaged across the study area; the variation of visible wood content was relatively small, with higher concentrations noted in Shelton Harbor compared to Oakland Bay (and an absence of wood along the center of the bay). Assuming an average wood content over the area of deposition (based on the core observations) and using the thickness of the recent deposition layer associated with wide-spread wood presence (based on the geophysical surveys), an estimated 240,000 cubic yards (183,500 cubic meters) of wood is present across the bay. This does not include areas of significant wood accumulation, discussed below. The single, well-defined, recent depositional layer was absent in Hammersley Inlet (due to input of coarse-grain material from outside of the Oakland Bay system), on the creek deltas (due to large amounts of recent sediment accumulation), and along the center of Oakland Bay where no sources were identified.

Table 5-2. Distribution of visible wood waste.

Core ID [a]	Wood Waste Thickness [b] (ft)	Average Wood Waste Content [c] (%)	Predevelopment Sediment Depth [d] (ft)
SH-01	1.0	10.0	5.0
SH-02	3.0	8.7	2.0
SH-10	4.0	12.5	3.0
SH-11	4.0	2.8	4.0
SH-14	3.0	10.0	2.0
SH-16	2.0	0.5	5.0
SH-19	2.0	1.0	3.0
SH-20	3.0	2.0	2.0
SH-23	3.0	8.3	2.0
SH-27	4.0	9.0	2.0
SH-28	4.0	11.3	3.0
OB-02	5.0	0.8	6.0
OB-03	NA	NA	5.0
OB-05	NA	NA	4.0
OB-07	4.0	5.3	2.0
OB-09	NA	NA	2.0
OB-10	3.0	0.3	5.0
OB-17	6.0	2.7	4.0
OB-18	3.0	8.7	2.0
OB-19	3.0	2.0	2.0
HI-04	4.0	2.0	3.0
Average	**3.3**	**5.4**	**3.2**

[a] Cores outside the geophysical survey area, those in deltas, and cores without recovery are not part of this analysis.

[b] Depth measured from the surface to the deepest point in the core at which wood waste was found; "NA", indicates no wood waste found and it was not compared in subsequent analyses.

[c] Average wood waste content based on percentages reported in 1-foot (0.3 meter) core samples.

[d] Predevelopment sediment depth areas based on interpolation between geophysical survey lines.

The post-development layer generally thins and decreases in wood waste content moving away from Shelton Harbor into southern Oakland Bay to the north, increasing again near Chapman Cove and the adjacent log storage lease area there (Figure 5-3; Appendix E, Figure C4 shows log rafts in the lease area). The recent depositional layer contains significant clayey silt and usually overlies a more consolidated, wood-free silty clay layer associated with predevelopment conditions (see core logs in Appendix B). In a few instances near the shoreline, the silt layer overlies sand, where the recent supply of sand has been lost due to disconnection of the bluffs along the shoreline by roadway construction and other development. The core log shown in Figure 5-5 indicates a cap of wood waste-free silt on top of older wood-containing sediments, another common feature in deeper portions of Oakland Bay, distant from modern wood waste sources. This cleaner cap, in places, indicates that most of the wood waste accumulation in these areas is from historical activities.

Wood waste generally was not found in Hammersley Inlet, where erosion processes leave only consolidated glacial sediments on the seabed. Where sediment does exist, it is usually much coarser than that found in most of Oakland Bay, suggesting that it is derived from erosion of nearby consolidated glacial sediments (e.g., where Oakland Bay and Hammersley Inlet meet). Wood waste also generally was not found in cores collected from creek deltas. At most creek deltas, it is likely that old wood waste deposits (where they occur) are buried by recently accumulated clean sediment.

5.2.3.2 *Concentrated Wood Waste Accumulations*

Significant wood waste accumulation was identified at four locations across the study area. A significant accumulation was determined to be total visible wood in excess of 20 percent by volume. Outside of these four locations, individual cores with 20 percent wood by volume occurred over short depth intervals, including SH-10 with 2 feet (0.6 meters) of 20 percent wood, the surface grab sample at SH-24 with 50 percent wood (no core could be collected due to refusal), SH-28 with 1 foot (0.3 meter) of 20 percent wood, and OB-7 with 1 foot (0.3 meter) of 20 percent wood. These cores were not considered to represent significant accumulations. The four locations with heavy wood accumulations were typically associated with known, historical sources of wood debris, and are described as follows:

- *Former pond saw*– This small wood accumulation area is located adjacent to the Simpson Planing Mill in shallow water, defined by core SH-04 (Figure 4-3). The nature of the wood waste was consistent with a mill byproduct (sawdust). High wood waste content (80 percent) was found between 2 and 6 feet (0.6 and 1.8 meters) deep, indicating an older deposition that has been covered by recent sediment build up (less than 5 percent wood content).

- *Railway log dump* – This wood accumulation area extends from the Simpson shoreline to the east, south of the rail line berm that keeps the creek flowing to the north, and is defined by cores SH-18, SH-21, and SH-22 (Figure 4-3). At sample station SH-18, high wood content (15 to 30 percent) was identified from the surface to 4 feet (1.2 meters) deep; no wood was seen in the bottom 2 feet (0.6 meters) of the core. At sample station SH-21, high wood content (25 to 70 percent) was initially identified extending from the surface to 5 feet (1.5 meters) deep. Sediment included increasing fiber content with depth, decreasing chips with depth, and the appearance of bark near the bottom.

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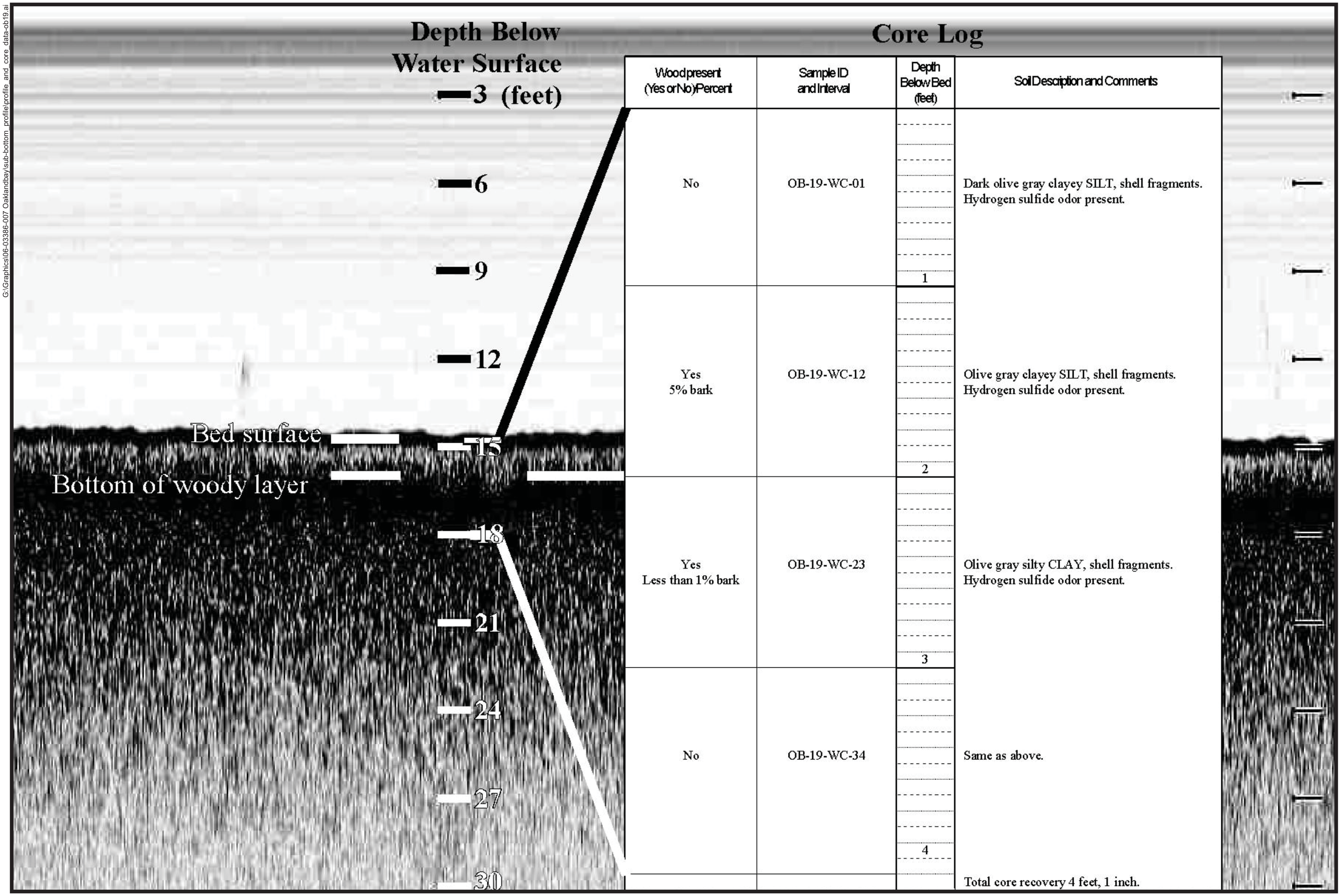

Core Log

Wood present (Yes or No) Percent	Sample ID and Interval	Depth Below Bed (feet)	Soil Description and Comments
No	OB-19-WC-01	1	Dark olive gray clayey SILT, shell fragments. Hydrogen sulfide odor present.
Yes 5% bark	OB-19-WC-12	2	Olive gray clayey SILT, shell fragments. Hydrogen sulfide odor present.
Yes Less than 1% bark	OB-19-WC-23	3	Olive gray silty CLAY, shell fragments. Hydrogen sulfide odor present.
No	OB-19-WC-34	4	Same as above.
			Total core recovery 4 feet, 1 inch.

Figure 5-5. Example of a sub-bottom profile and accompanying core data (OB-19).

The second, deeper core advanced at that station indicated only moderate wood content (20 to 25 percent) in the top 4 feet (1.2 meters) and 5 percent or less wood extending to the bottom at 12 feet (3.7 meters). Nearby station SH-22 identified high wood content (40 percent, all bark) in the 2-3 core section before the core tube encountered refusal; additional attempts could not advance the core tube past 2 feet (0.6 meters) due to high wood content. It appears that significant wood waste exists in this area, but that it is distributed unevenly.

- *Former sawmill #4* – This small wood accumulation area was located adjacent to former sawmill #4, defined by core SH-12 (Figure 4-3). High wood content (65 percent) was initially identified at 5 feet (1.5 meters) deep as fiber (50 percent), bark (10 percent), and chips (5 percent). Wood content above the 5 foot (1.52 meter) mark was primarily fiber at 10 percent. The second, deeper core advanced at that station indicated fiber from less than 5 percent to 10 percent in the first 5 feet (1.5 meters) and then 75 to 100 percent sawdust to 10.5 feet (3.2 meters). The nature of the deeper wood waste is consistent with mill operations. Current nearby loading of wood chips to barges, observed during sampling, led to expectations of high wood content at nearby station SH-11, but less than 5 percent wood was noted in the top 4.5 feet (1.4 meters); no deep core was advanced.
- *Head of Bay* – The wood accumulation area immediately north of Bayshore Point was identified by core OB-12; the three other sample stations in the head of the bay were spread wide apart and contained very little wood. High wood content (75 to 100 percent) was initially identified between 3 and 5 feet (0.9 and 1.5 meters) deep as sawdust. A small amount of bark (less than 5 percent) was noted only in the 1-2 foot core section above. The second, deeper core advanced at that station indicated 50 to 100 percent sawdust from 4 to 9.5 feet (1.2 to 2.9 meters) and 5 percent bark in the 1-2 foot core section. The nature of the deeper wood waste is consistent with mill operations. An 1889 map of Oakland Bay identified Willey's Mill located directly across the bay on the eastern shoreline (Fredson 1976). The history of this mill is not known. No evidence of an historical mill adjacent to the sample station was found.

Cores did not reach the bottom of most of these wood deposits and the limited number of sampling stations did not allow for accurate mapping of their aerial extents. Table 5-3 provides estimates of wood volume at each location based on the minimum depth of wood found in the representative core(s) multiplied by an assumed areal extent of each area of accumulation, estimated from a combination of geophysical survey results and proximity to cores not exhibiting large quantities of wood. The extents of the three Shelton Harbor areas of accumulation (former pond saw, railway log dump, and former sawmill#4) are well constrained by a dense network of adjacent (clean) cores; however, the size of the Head of Bay accumulation is not well known, due to the lack of nearby cores and no geophysical data.

Table 5-3. Wood waste volume estimates in high accumulation areas.

Name	Cores In Accumulation Area	Bottom Reached	Approximate Area of Wood Waste Accumulation (ft^2) [acres]	Minimum Average Thickness [b] (ft)	Minimum Total Volume of Deposit (cubic yards)	Average Wood Waste Content (%)	Minimum Wood Waste Volume (cubic yards)
Former Pond Saw	SH-04	No	45,000 [1.0]	6.7	11,167	50.3	5,617
Railway Log Dump	SH-18, SH-21, SH-22	No [a]	800,000 [18.4]	6.2	183,704	45.7	83,953
Former Sawmill #4	SH-12	No	45,000 [1.0]	10.4	17,333	33.4	5,789
Head of Bay	OB-12	No	N/A	9.3	N/A	46.7	N/A
Total			**890,000 [20.4]**		**212,204**		**95,359**

[a] Bottom of wood reached in core SH18, but not in SH-21 and SH-22.

[b] Depth of core penetration in those samples where bottom of wood was not found; where multiple cores found considerable wood, average depth of wood encountered was used.

N/A Not available

Total volume estimates assume that the average concentration of wood waste visually identified in the core(s) is typical of the entire wood accumulation area. The total estimate of approximately 95,359 cubic yards (72,900 cubic meters) should be considered a rough minimum estimate, since the total depth of the wood waste in portions of these areas could be much greater than that observed in the cores (plus, the Head of Bay area could not be reliably estimated).

5.3 Sediment and Wood Transport Patterns

Wood waste is transported within the bay in much the same way as sediment. However, while sediment enters the bay energetically through creek discharge, wood enters vertically through the water column at log raft and spillage or dumping locations. As such, wood material is not transported vigorously from where it is initially delivered to the water, remaining near its original sources. When it is transported, wood material moves toward deeper portions of Oakland Bay, where it is mixed with sediment and accumulates at low concentrations. In Shelton Harbor, transport is more complicated, due to the numerous and spatially concentrated sources of wood waste in that area. It does appear that some of the wood introduced to the harbor escapes to the central portion of Oakland Bay, based on the interpretation that sediment moves from the harbor to the bay and that low concentrations of wood are present in areas where historical activities were absent. The primary difference between the distribution and transport of sediment and wood waste is that the sources of wood waste are more numerous than sources of sediment.

5.4 Distribution of Chemical Compounds in Surface Sediments

Fifty surface grab samples were collected across the study area; samples could not be collected at three of the originally planned 53 locations. Additionally, three reference sediment surface grab samples were collected from Carr Inlet. Samples were analyzed for the following to evaluate the potential presence of chemicals associated with industrial activities and decaying wood:

- Conventional analytes grain size, ammonia, total sulfides, TOC, and TVS (TVS was measured only at 16 wood waste sample stations)
- Dioxins/furans
- PCBs
- Chlorinated pesticides
- SVOCs
- Metals
- Resin acids and guaiacols (tested only at 16 wood waste sample stations and resin acids at eight selected archived non-wood waste locations in Oakland Bay and Hammersley Inlet)
- TBT (at three selected locations near marine railway and marina)
- Petroleum hydrocarbons (at eight selected locations near areas of historic petroleum usage or stormwater runoff)

5.4.1 Conventional Analytes

Conventional parameters (grain size, ammonia, total sulfides, TOC) were measured at all surface locations across the bay; TVS was measured at the 13 designated wood waste locations in Shelton Harbor and 3 designated wood waste locations Oakland Bay.

Grain size results, represented as gravel, sand, silt, and clay fractions, are shown on Figure 5-6. Sand was the major fraction in 54 percent of the surface locations across the entire site (27 of 50 total locations). The sandy locations were primarily located in Hammersley Inlet (sand fraction ranging from 79.7 to 95.6 percent), along the southwest shoreline and southern portion of Oakland Bay (sand fraction ranging from 40.1 to 77.5 percent), and in outer and northern Shelton Harbor (sand fraction ranging from 44.1 to 96.2 percent). Locations closer to the mouth of Goldsborough Creek and near shellfish areas in upper Oakland Bay and Chapman Cove contained more gravel, ranging from 20.9 to 36.3 percent. Greater than 45 percent total fines (i.e., silt and clay fractions combined) were found near the mouth of Shelton Creek, across the southern portion of Shelton Harbor, Chapman Cove, and in the middle and along the southeast shoreline of Oakland Bay.

Ammonia is a common byproduct of bacterial degradation of wood waste or organic-rich plant and animal materials. Ammonia concentrations are shown on Figure 5-7. As shown in Table 4-1, mean ammonia concentrations measured in surface sediment from Shelton Harbor (12.9 mg/kg), Oakland Bay (9.81 mg/kg), and Hammersley Inlet (7.12 mg/kg), were similar to results from the reference sediment area (12.1 mg/kg). Maximum detected values were slightly higher in Shelton Harbor (32.4 mg/kg) and Oakland Bay (22.4 mg/kg) than the reference sediment area (14.4 mg/kg).

Two of the four sampling stations exhibiting relatively high ammonia content (>20 mg/kg) had visible wood present, 10 of 19 sampling stations with medium level ammonia content (10 to 20 mg/kg) had visible wood present, and 11 of 27 sampling stations with relatively low ammonia content (<10 mg/kg) had visible wood present.

Sulfides are also a common byproduct of bacterial degradation of wood waste. Accumulation of sulfides in sediment may also occur in areas with restricted water circulation (e.g. terminal inlets), particulate organic input, and water column density stratification associated with discharge plumes from creeks. Sulfide concentrations are shown on Figure 5-8. The highest concentrations of total sulfides were found in surface sediments throughout the southwest portion of Shelton Harbor and along the shoreline and middle of Oakland Bay. The station with the highest sulfide concentrations (SH-21) corresponds with a wood waste accumulation area identified on Figure 5-2. Mean concentrations of total sulfides in surface sediment in Shelton Harbor (661 mg/kg) and Oakland Bay (666 mg/kg) were greater than the mean reference sediment result (168 mg/kg); the mean concentration of total sulfides in surface sediment in Hammersley Inlet (82.3 mg/kg) was less than the mean concentration in the reference sediment area (see Table 4-1).

Fifteen of the 34 sampling stations exhibiting relatively high sulfides content (>200 mg/kg) had visible wood present, all six sampling stations with medium level sulfides content (20 to 200 mg/kg) had visible wood present, and seven of 10 sampling stations with relatively low sulfides content (<20 mg/kg) had visible wood present.

TOC may be elevated in areas with organic debris, such as wood waste. TOC concentrations are shown on Figure 5-9. TOC content in sediments collected from Shelton Harbor was generally high, with a mean value in surface sediment of 3.20 percent (see Table 4-1). The maximum TOC concentration found in Shelton Harbor was 11.0 percent at station SH-13. In general, TOC values above 4 percent were found along the shoreline in the former pond saw area (stations SH-03, SH-04, and SH-05) and throughout the southwest portion of Shelton Harbor (stations SH-11 through SH–14, and SH-18 through SH-24). This also corresponds to locations with total fines greater than 45 percent. In general, TOC content was less than 2 percent in Hammersley Inlet and was less than 4 percent in Oakland Bay. One surface sediment sample (OB-06) collected from along the eastern shoreline of Oakland Bay, where logs were once rafted, had TOC content above 4 percent.

Nine of 10 sampling stations exhibiting relatively high TOC content (>4 percent) had visible wood present and 14 of 40 sampling stations with medium level TOC content (0.05 to 4 percent) had visible wood present; no sampling stations exhibited low TOC content (<0.05 percent).

TVS was analyzed in surface sediment samples at 13 locations in Shelton Harbor and at 3 locations in Oakland Bay. These were designated as wood waste samples before sampling, based on expectations of finding wood accumulations in these areas (wood was not evident at five of the 16 locations). TVS is used as a method to determine relative amounts of wood waste present; it measures the total combustible content of a sample, expected to be primarily composed of wood. Mean TVS values for surface sediment in Shelton Harbor and Oakland Bay

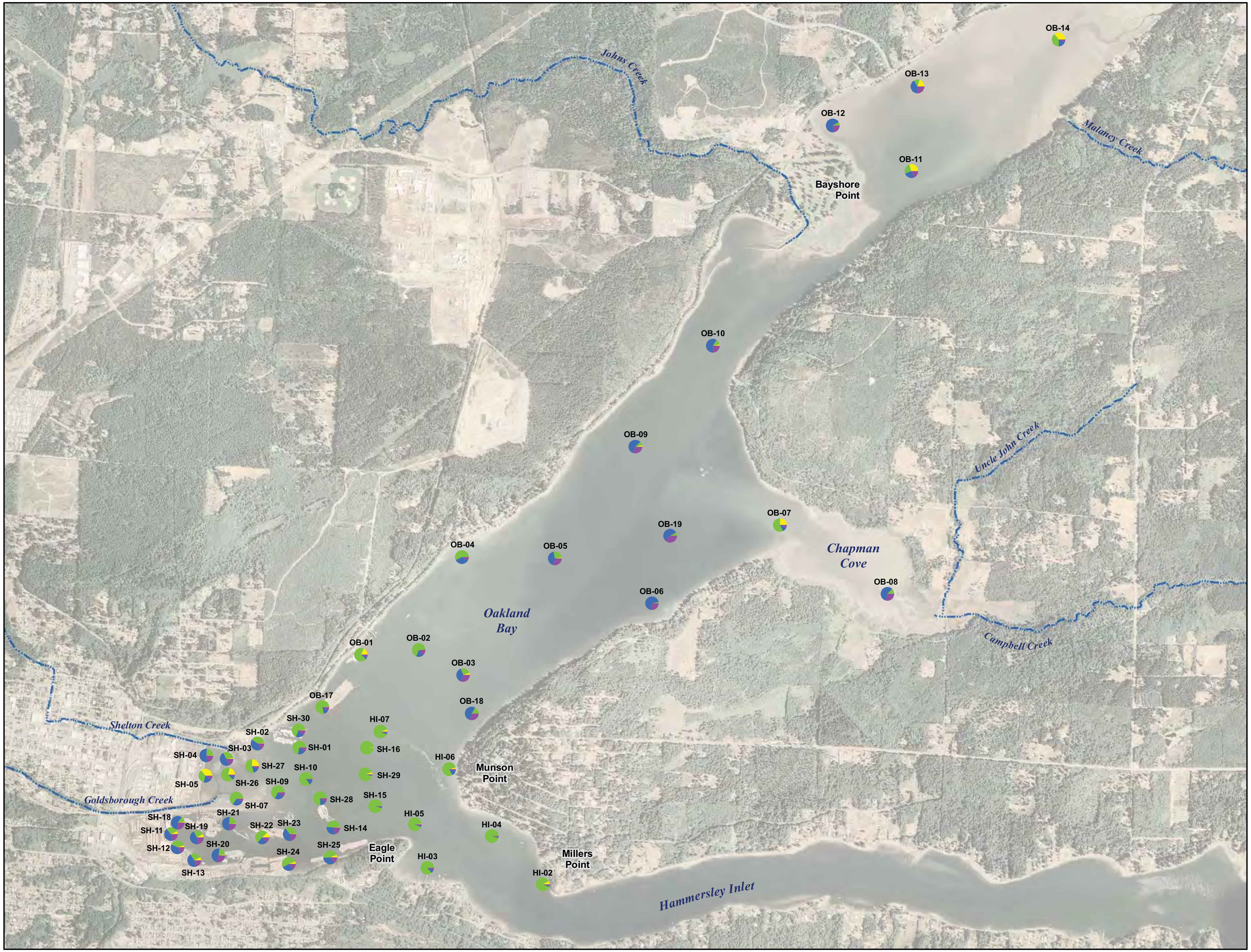

Figure 5-6.
Surface sample grain size distribution, across the Oakland Bay study area.

Legend

🟨 Gravel

🟩 Sand

🟦 Silt

🟪 Clay

N

0 1,050 2,100 4,200 Feet

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Aerial: USDA, 2006

Produced By: GIS (rdr)
Project: K:\Projects\06-03386-007\Project\Result_Figures\Grain_Size_Distribution-11x17.mxd

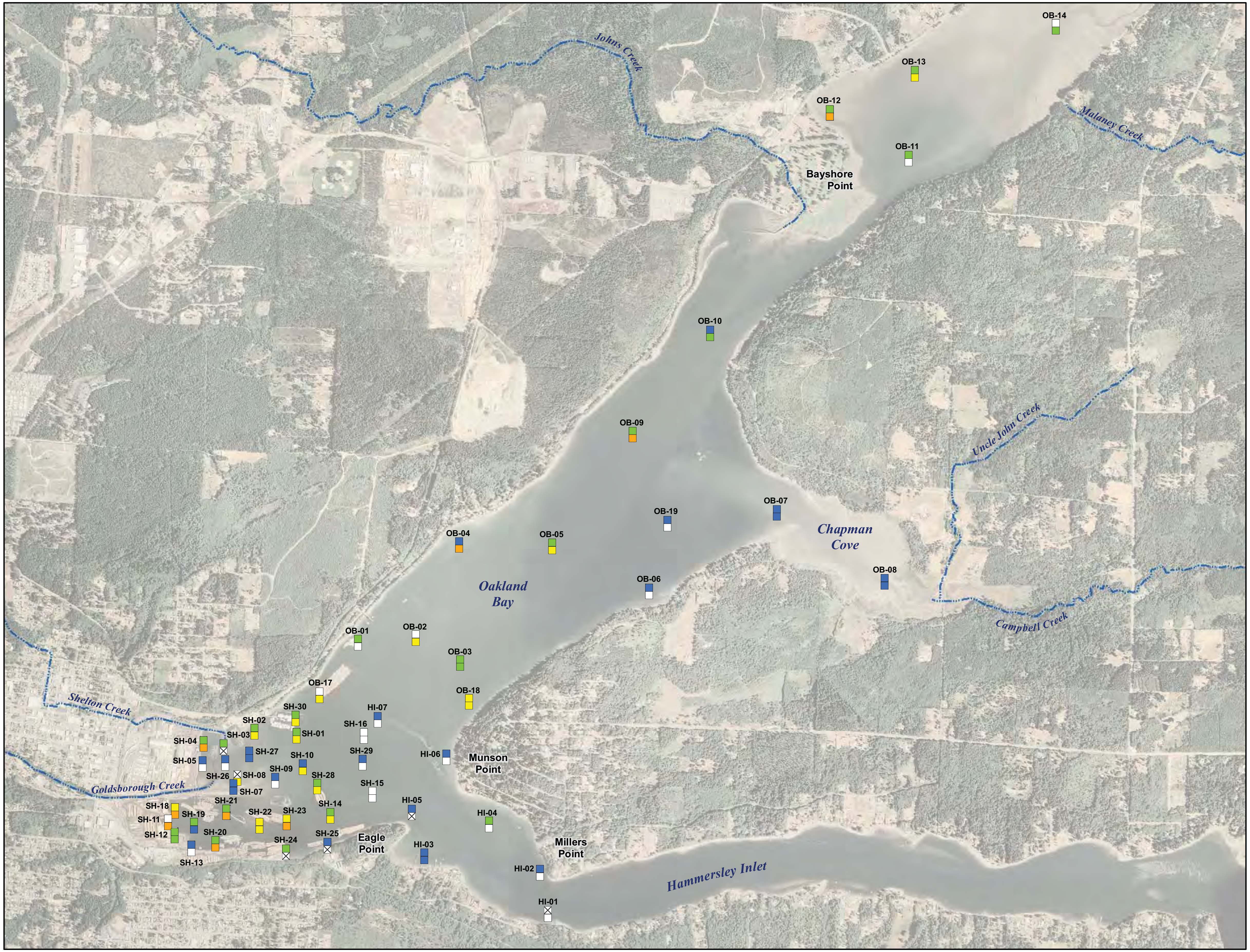

Figure 5-7.
Surface and subsurface sample ammonia distribution across the Oakland Bay study area.

Legend

Total ammonia (mg/kg)

□ 0.1 to 5

🟦 5 to 10

🟩 10 to 20

🟨 20 to 50

🟧 >50

☒ No data

Collected Sample Depth

Surface sample (top 0.3 feet)

1-2 feet

N

0 1,050 2,100 4,200 Feet

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Aerial: USDA, 2006

Produced By: GIS (rdr)
Project: K:\Projects\06-03386-007\Project\Result_Figures\Ammonia_results-11x17.mxd

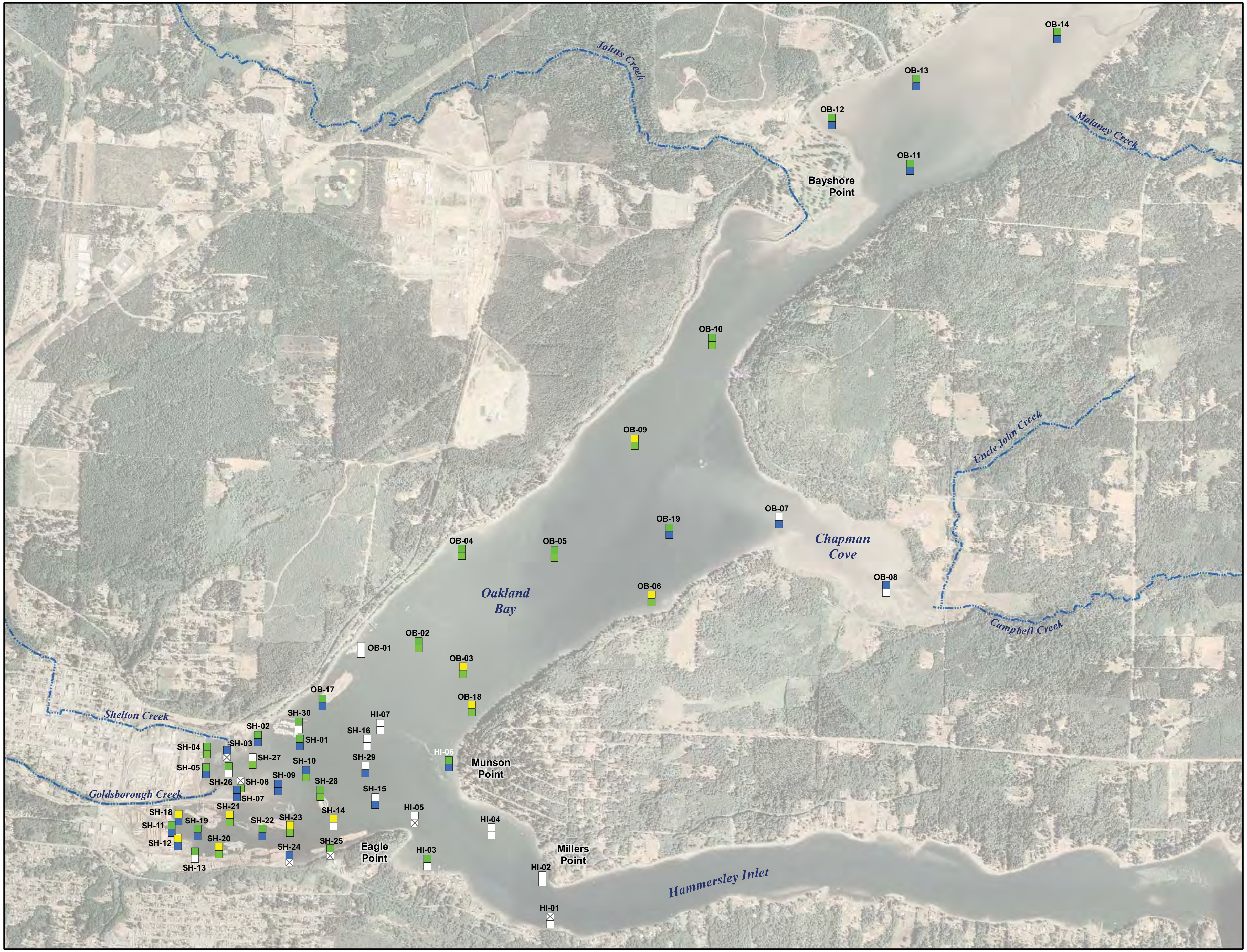

Figure 5-8.
Surface and subsurface sample sulfide distribution across the Oakland Bay study area.

Legend

Sulfide (mg/kg)

- ⬜ < 20, no effect
- 🟦 20 to 200, minor effects
- 🟩 200 to 1000, max proposed level for open disposal
- 🟨 > 1000

Collected Sample Depth

Surface sample
(top 0.3 feet)
1-2 feet

N

0 1,050 2,100 4,200
Feet

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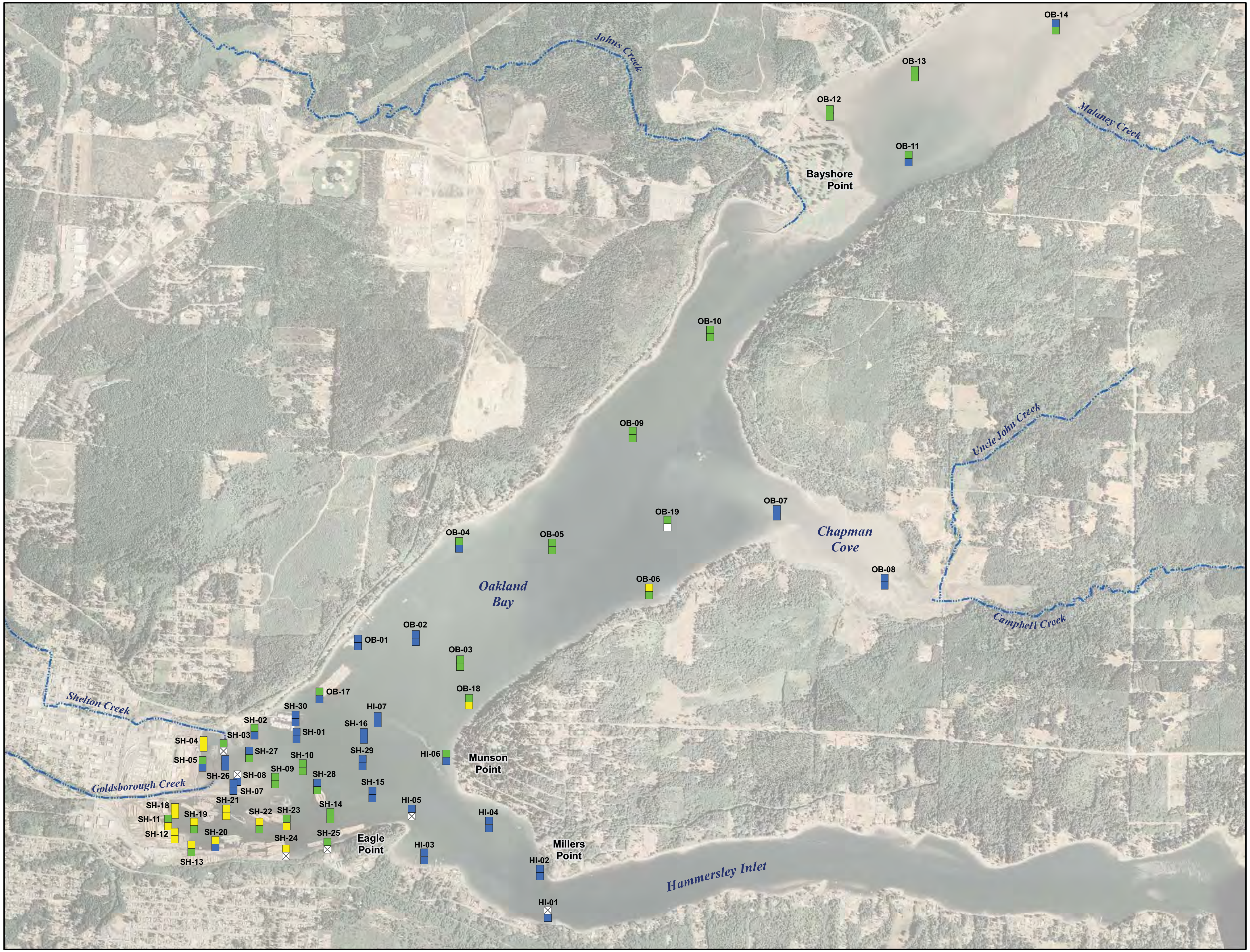
Aerial: USDA, 2006

Produced By: GIS (rdr)
Project: K:\Projects\06-03386-007\Project\Result_Figures\Sulfide_concentration-11x17.mxd

Figure 5-9.
Surface and subsurface sample total organic carbon distribution across the Oakland Bay study area.



Legend

Total organic carbon (%)

☐ < 0.05

🟦 0.05 to 2

🟩 2 to 4

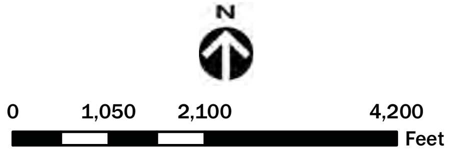
🟨 > 4

☒ No data

Collected Sample Depth

Surface sample (top 0.3 feet)

1-2 feet



HERRERA ENVIRONMENTAL CONSULTANTS

Aerial: USDA, 2006

Produced By: GIS (rdr)
Project: K:\Projects\06-03386-007\Project\Result_Figures\Total_organic_carbon-11x17.mxd

were 10.6 and 7.67 percent, respectively, with maximum concentrations of 19.7 and 9.35 percent, respectively (Table 4-1). In general, TVS values were highest throughout the southwest portion of Shelton Harbor (stations SH-18 through SH-25) and along the eastern shoreline of Oakland Bay (stations OB-18 and OB-19 – although only three stations in Oakland Bay were tested for TVS). The mean TVS at the reference stations was 2.0 percent, with a maximum reference location of 2.6 percent. The highest concentration in Shelton Harbor, at SH-22, corresponds to a wood waste accumulation area identified on Figure 5-2.

Seven of eight sampling stations exhibiting relatively high TVS content (>10 percent) had visible wood present, none of four sampling stations with medium level TVS content (5 to 10 percent) had visible wood present, and two of four sampling stations exhibiting relatively low TVS content (<5 percent) had visible wood present.

5.4.2 Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans

Dioxins/furans were detected in all surface sediment samples. The mean total dioxin TEQ result was highest in Shelton Harbor (42.8 ng/kg TEQ);, mean total dioxin TEQ results for Oakland Bay (32.1 ng/kg TEQ) and Hammersley Inlet (5.42 ng/kg TEQ) were also both elevated compared to the reference sediment samples (0.482 ng/kg TEQ) (see Table 4-1).

Dioxins/furans do not have numerical criteria under SMS, but two benchmark values (4.0 and 10 ng/kg TEQ) were used for this investigation to graphically display total dioxin TEQ result distributions (Figure 5-10). The first benchmark value of 4.0 ng/kg TEQ is the proposed (interim) Puget Sound-wide background level based on an upper bound estimate of the distribution of dioxin in non-urban areas (DMMP 2010; USACE 2009), and the second benchmark value of 10 ng/kg TEQ is the draft maximum concentration allowable for open-water disposal under DMMP. The OSV Bold Study (USACE 2009) monitored ambient dioxin concentrations in sediments at background reference areas throughout Puget Sound.

Additional benchmarks of 10 to 20, 20 to 60, 60 to 100, and 100 to 200 ng/kg were also indicated on the figure. Dioxin TEQ concentrations are depicted as low (white and blue), medium (yellow and green), and high (orange and pink) relative to the range of values found during this investigation; however, all medium and high values should be considered as high within the context of evaluating potential action levels.

Dioxins/furans were identified in surface sediment at all 50 locations sampled, ranging from 1 to 175 ng/kg TEQ. The following surface sediment observations from Figure 5-10 can be made:

- The highest concentrations were found at five locations along the western edge of Shelton Harbor where the majority of wood processing has historically taken place, including wood waste burning, sulfite liquor discharge and burning, and PCP use.

- Medium level concentrations were found to be distributed across the entire study area, except for Hammersley Inlet.

- Low level concentrations were found to be distributed in areas of high sedimentation (creek deltas), where mixing likely has occurred (the southwest shore of Shelton Harbor), and along the perimeter of Hammersley Inlet and Oakland Bay where sediment does not accumulate.

High dioxin TEQ concentrations throughout Shelton Harbor and Oakland Bay relative to the greater Puget Sound indicate a local source area. Sediment transport analysis results and generally consistent chemical concentrations observed across Oakland Bay indicate that once dioxins/furans enter the system, they do not leave the system.

5.4.3 Polychlorinated Biphenyls

PCBs were measured in all surface samples, and were detected in surface sediment at two locations, Aroclor 1260 was detected at the Shelton Marina (SH-01) and a mixture of Aroclors 1260 and 1016 was detected near Munson Point (HI-06). Concentrations at both locations were well below SMS criteria (see Appendix G).

5.4.4 Chlorinated Pesticides

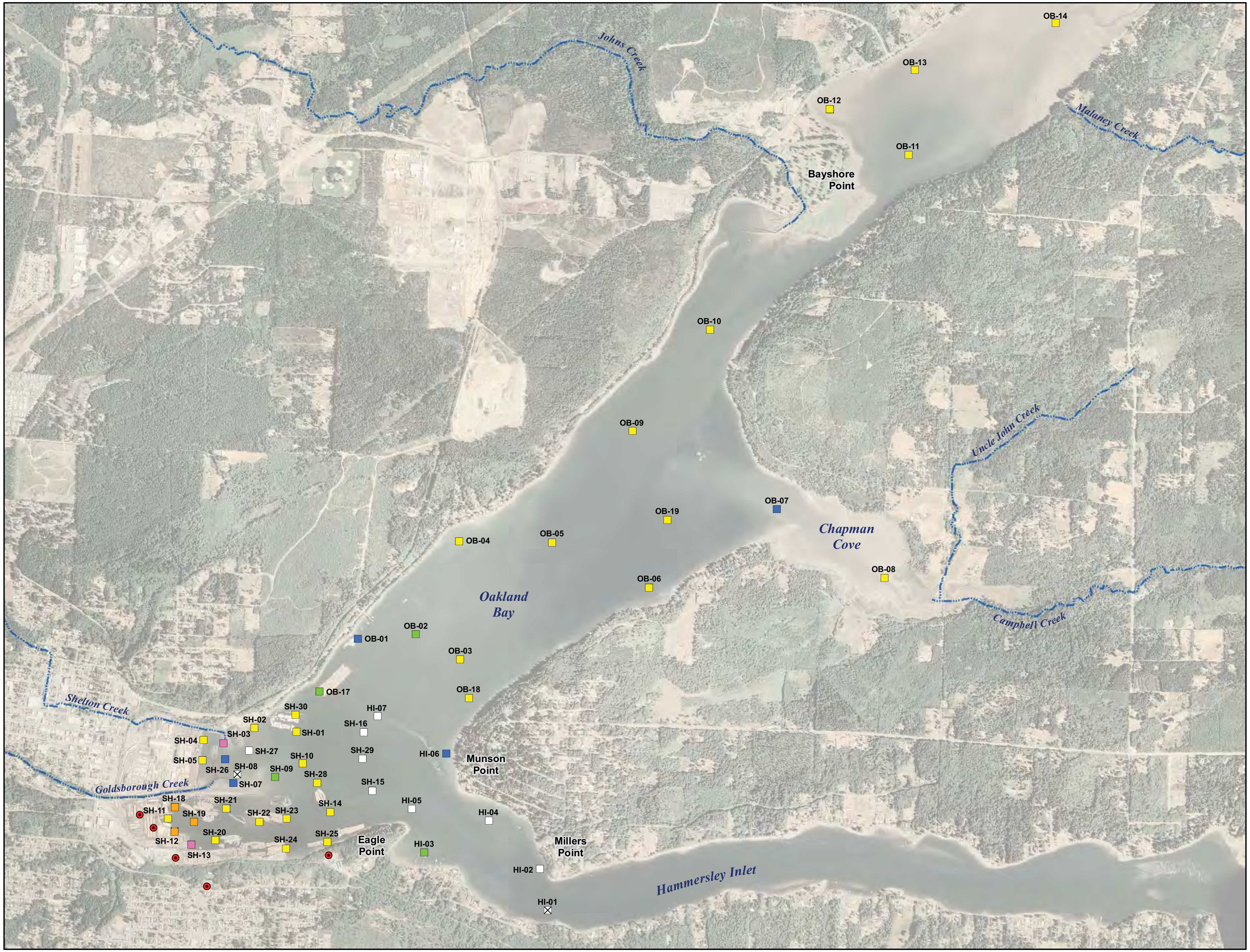
Chlorinated pesticides were measured in all surface samples. In general, low levels of chlorinated pesticides were found in surface sediment across Shelton Harbor, Oakland Bay, and Hammersley Inlet (see Table 4-1). The most common compound found was 4,4’-DDT and associated breakdown products (4,4’-DDD and 4,4’-DDE). Aldrin and alpha-chlordane were found in Shelton Harbor surface sediments, but not in Oakland Bay or Hammersley Inlet. No LAET criteria (established only for DDT, DDD, and DDE) were exceeded (see Appendix G).

5.4.5 Semivolatile Organic Compounds: PAHs, Phthalates, and Phenols

SVOCs were measured in all surface samples. The most common SVOCs detected in surface sediments were PAHs. Total LPAHs were detected in 67 percent of Shelton Harbor surface sediment samples, 12 percent of Oakland Bay surface sediments samples, and were not detected in Hammersley Inlet surface sediment samples. Total HPAHs were detected in 89 percent of Shelton Harbor surface sediment samples, 41 percent of Oakland Bay surface sediments samples, and 17 percent of Hammersley Inlet surface sediment samples (see Table 4-1). No detected SVOCs exceeded SQS criteria; one sample exceeded the LAET criterion for fluoranthene in Shelton Harbor. Detection limits for 2,4-dimethylphenol and hexachlorobenzene exceeded SMS criteria; however, these compounds were not detected at any sample location (see discussion in Section 4.2).

In Shelton Harbor, total low molecular weight polycyclic aromatic hydrocarbon (LPAH) and high molecular weight polycyclic aromatic hydrocarbon (HPAH) concentrations were highest near the former marine railway and in the southwest portion of harbor. In general, PAH concentrations decrease to the east, leaving Shelton Harbor.

Figure 5-10.
Surface sample dioxin distribution across the Oakland Bay study area.



Legend

● Historic emission stack

Dioxin (TEQ) (ng/kg)

□ < 4

🟦 4 to 10

🟩 10 to 20

🟨 20 to 60

🟧 60 to 100

🟪 100 to 200

☒ No data

Note: Surface samples collected from top 0.3 feet.

N

0 1,050 2,100 4,200
Feet

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Low-level total LPAHs and HPAHs were detected in Oakland Bay surface sediments north of the Shelton Marina (OB-17 and OB-04), near Chapman Cove (OB-07), and in upper Oakland Bay (OB-12 and OB-13; only total HPAHs were detected); LPAHs and HPAHs were not detected in any other surface sediment samples in Oakland Bay. Total HPAHs were detected in one surface sediment sample from Hammersley Inlet (HI-03), located in a depositional area.

Two phthalate compounds, BEHP and butylbenzylphthalate, and two phenols (4-methylphenol and phenol) were detected at low levels in surface sediment samples. BEHP was found throughout Shelton Harbor and lower Oakland Bay, while butylbenzylphthalate was detected at only one location near the mouth of Shelton Creek (SH-03).

Phenol was found near Shelton Marina, throughout the southern portion of Shelton Harbor, and in portions of Oakland Bay and Hammersley Inlet. Pentachlorophenol was not detected in any surface or subsurface sample in this study. However, in the 2000 Reconnaissance Survey of Inner Shelton Harbor Sediments, pentachlorophenol was detected in 9 of 10 surface chemical screening locations in Shelton Harbor, with concentrations ranging from 100 to 400 ppb (Ecology 2000).

No other SMS SVOC compounds were detected above laboratory reporting limits in any surface sediment samples across the study area.

5.4.6 Resin Acids and Guaiacols

Resin acids and guaiacols are byproducts of wood waste decomposition and the pulp industry, and were analyzed at 13 wood waste sample stations within Shelton Harbor and 3 wood waste stations within Oakland Bay. Eight additional surface sediment samples in Oakland Bay and Hammersley Inlet were selected for analysis of resin acids after initial sample results were received. One or more resin acid compounds were detected in all surface wood waste sediment samples analyzed; no guaiacol compounds were detected in any samples. The most common resin acid compounds detected in surface sediment samples collected in Shelton Harbor and Oakland Bay were abietic acid, dehydroabietic acid, oleic acid, and retene. In addition, linolenic acid was detected in approximately 50 percent of the Shelton Harbor surface sediment samples, 11 percent of Oakland Bay surface sediment samples, and in all of the Hammersley Inlet surface sediment samples. The only resin acid compounds detetected in Hammersley Inlet surface sediment samples were linolenic acid and oleic acid.

There are no numerical SMS criteria for resin acids. To compare concentrations across the site, resin acid compounds were summed to provide a total resin acid concentration. As shown in Table 4-1, total resin acids are present in Shelton Harbor at a level twice the value in Oakland Bay, based on mean concentration (3,300 µg/kg in Shelton Harbor and 1,500 µg/kg in Oakland Bay). The highest total resin acid concentrations are present in the south and southwest portion of the harbor. The highest total resin acid concentration (9,000 mg/kg) was found at location SH-24, on the southern shoreline of Shelton Harbor where logs have been stored and handled for many years. Wood waste was found at this location; however, other surface sediment stations with high total resin acid values do not directly correspond to areas of wood waste accumulation identified in Figure 5-2. The presence of resin acids may also be associated with the historical discharges of sulfite liquor from the Rayonier pulp mill, as resin acids are known to be present in high concentrations in pulp mill waste liquor.

All four sampling stations exhibiting relatively high resin acid content (>3,500 µg/kg) had visible wood present, six of 11 sampling stations with medium level resin acid content (1,500 to 3,500 µg/kg) had visible wood present, and one of eight sampling stations exhibiting relatively low resin acid content (<1,000 µg/kg) had visible wood present.

5.4.7 Tributyltins

TBTs were analyzed at three locations near the marina and former marine railway, based on results of the 1999 Reconnaissance Survey. TBTs were found in surface sediment at SH-02, south of the vessel haul out at the end of the Pine Street right of way (public boat ramp). The concentrations measured at SH-02 (8.0 µg/kg butyltin ion, 30 µg/kg dibutyltin ion, and 13 µg/kg tributyltin ion) were all well below concentrations found during the Reconnaissance Survey (concentrations near the base of the launching rails were 1,300 µg/kg butyltin ion, 4,100 µg/kg dibutyltin ion, and 1,500 µg/kg tributyltin ion) (Ecology 2000).

TBTs were not detected at locations near the Shelton Marina (SH-01 and SH-30).

5.4.8 Metals

Metals were detected at low levels in all samples across the project site; however, no values exceeded SMS criteria. In general, mean concentrations of metals in surface sediment samples were similar in Shelton Harbor and Oakland Bay, and slightly lower in Hammersley Inlet, which were similar to reference sediment samples (see Table 4-1).

The highest concentrations of metals were found in Shelton Harbor near the sawdust loading area (SH-11, SH-18, and SH-19).

5.4.9 Petroleum Hydrocarbons

Petroleum hydrocarbons were analyzed in sediment from eight locations along the Shelton Harbor and Oakland Bay shorelines where historical use had been noted. Lube oil- range hydrocarbons were found at a concentration of 220 mg/kg in the surface sediment sample collected at station SH-05, located on the western shoreline of Shelton Harbor; petroleum hydrocarbons were not detected in any other surface sediment samples.

5.5 Distribution of Chemical Compounds in Subsurface Sediments

A total of 48 subsurface cores were collected across the study area for chemical analyses; core samples could not be collected at 5 of the planned 53 subsurface locations. Additionally, three cores were collected for radioisotope analyses (discussed in Section 5.2.2). Sediment cores were separated into 1 foot (0.3 meter) lengths; and subjected to analysis as described below: Initially all 1 foot (0.3 meter) core sections below 1-2 feet were frozen and archived for possible future analysis. Based on surface sediment results, selected 1-2 foot and 2-3 foot core sections were later analyzed for dioxins/furans.

- All 1-2 foot cores were analyzed for conventional analytes grain size, ammonia, total sulfides, and TOC. TVS was analyzed only at 14 wood waste sample stations.
- All 1-2 foot cores from Shelton Harbor, and from three wood waste locations within Oakland Bay were analyzed for:
  - ☐ PCBs
  - ☐ Chlorinated pesticides
  - ☐ SVOCs
  - ☐ Metals
- All 1-2 foot cores from 11 designated wood waste stations in Shelton Harbor and 3 wood waste locations in Oakland Bay were tested for resin acids and guaiacols.
- Selected archived samples from 1-2 and/or 2-3 feet were later tested for dioxins/furans.
- TBT (at three selected locations near marine railway and marina)
- Petroleum hydrocarbons (at two selected locations near areas of former petroleum usage)

5.5.1 Conventional Analytes

Conventional parameters (ammonia, total sulfides, TOC) were measured at all subsurface locations across the bay. TVS was measured at wood waste sample locations in Shelton Harbor (11 locations) and Oakland Bay (three locations) where accumulation of wood was anticipated.

Ammonia concentrations are shown on Figure 5-7. As shown in Table 4-1, mean ammonia concentrations measured in subsurface sediment from Shelton Harbor (31.1 mg/kg) and Oakland Bay (26.7 mg/kg) were higher than Hammersley Inlet (2.53 mg/kg). Maximum detected values were slightly higher in Shelton Harbor (113 mg/kg) than Oakland Bay (75.5 mg/kg). Mean concentrations in subsurface samples were almost three times higher than surface samples in Shelton Harbor and Oakland Bay and three times lower than surface samples in Hammersley Inlet.

Fifteen of the 22 sampling stations exhibiting relatively high ammonia content (>20 mg/kg) had visible wood present, two of four sampling stations with medium level ammonia content (10 to

20 mg/kg) had visible wood present, and 10 of 22 sampling stations with relatively low ammonia content (<10 mg/kg) had visible wood present.

Total sulfides concentrations are shown on Figure 5-8. As shown in Table 4-1, mean concentration of total sulfides in subsurface sediment was significantly higher in Shelton Harbor (194 mg/kg) and Oakland Bay (181 mg/kg) compared to Hammersley Inlet (32.0 mg/kg). Mean concentrations in subsurface samples were approximately one-third the surface sample concentrations across the study area.

Eight of the 16 sampling stations exhibiting relatively high sulfide content (>200 mg/kg) had visible wood present, 14 of 20 sampling stations with medium level sulfide content (20 to 200 mg/kg) had visible wood present, and 5 of 12 sampling stations with relatively low sulfide content (<20 mg/kg) had visible wood present.

TOC concentrations are shown on Figure 5-9. TOC content in subsurface sediments collected from Shelton Harbor were elevated, with mean values in subsurface sediment of 3.03 percent (see Table 4-1). Maximum TOC concentrations found in Shelton Harbor were 11.1 percent at station SH-21, which corresponds to areas of wood waste accumulation identified on Figure 5-2. In general, TOC values above 4 percent were found along the western shoreline (stations SH-04, SH-18, SH-11, and SH-12) and in log rafting areas south of the railway log dump (SH-21 and SH-23). One subsurface sediment sample (OB-08) collected from along the eastern shoreline of Oakland Bay where logs are rafted also had TOC content above 4 percent. Mean concentrations of subsurface samples were generally comparable to surface concentrations in Shelton Harbor and Oakland Bay, and approximately one-half the mean surface concentration of Hammersley Inlet.

Six of the seven sampling stations exhibiting relatively high TOC content (>4 percent) had visible wood present, 16 of 30 sampling stations with medium level TOC content (0.05 to 4 percent) had visible wood present, and five of 11 sampling stations with relatively low TOC content (<0.05 mg/kg) had visible wood present.

Mean TVS values for subsurface sediment in Shelton Harbor and Oakland Bay were 12.6 and 10.7 percent, respectively, with maximum concentrations of 39.5 and 13.6 percent (see Table 4-1). In general, TVS values were highest throughout the southwest portion of Shelton Harbor (stations SH-18 through SH-23) and along the eastern shoreline of Oakland Bay (stations OB-18 and OB-19 – although only three stations were tested). The highest value for TVS occurred at station SH-21, located in an area of wood waste accumulation (Figure 5-2). Subsurface TVS mean concentrations were slightly higher than surface mean concentrations in both areas.

All five sampling stations exhibiting relatively high TVS content (>10 percent) had visible wood present, all five sampling stations with medium level TVS content (5 to 10 percent) had visible wood present, and one of three sampling stations exhibiting relatively low TVS content (<5 percent) had visible wood present.

5.5.2 Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans

Subsurface sediment samples were analyzed for dioxins/furans at seven stations located in Shelton Harbor and five stations located in Oakland Bay, based on relatively high concentrations first found in surface samples (Figure 5-11). Samples were analyzed representing either the 1-2 foot or 2-3 foot core sections (both core sections were analyzed at two locations in Shelton Harbor along the western shore, resulting in a total of 14 samples); dioxins/furans were detected in every sample. The mean total dioxin TEQ result was higher in Shelton Harbor, based on seven samples from 2-3 foot depth and two samples from 1-2 foot depth (198 ng/kg TEQ), than Oakland Bay, based on 5 samples from the 1-2 foot depth (97.8 ng/kg TEQ); These were well above mean surface sediment values of 42.8 and 32.1 ng/kg TEQ, respectively (see Table 4-1).

Higher dioxin/furan concentrations found at depth at 10 of the 12 stations sampled across the study area (including the head of the bay) indicates higher historical input levels. With only two sample depths analyzed at each location, it is not possible to correlate concentration trends with time, other than to suggest that dioxin input to the bay has decreased in the recent past. It is not known why surface sediments continue to contain dioxin. This could be related to disturbance/mixing of the sediments by natural or man-influenced actions; redistribution of sediments from higher-concentration areas by currents, or an ongoing source of dioxin.

Due to a lack of concentration gradients moving away from potential shoreline inputs, dioxins/furans appear to have been disbursed by both aerial and fluvial processes. Once incorporated into sediments, there has been little movement out of the Oakland Bay system. The two locations with higher concentrations at the surface versus the subsurface include one in the Goldsborough Creek alluvial fan with coarser-grain material at depth and along the southwest shoreline with a high potential for mixing to occur associated with historical dredging activities.

5.5.3 Polychlorinated Biphenyls

All samples from 1-2 foot depth within Shelton Harbor and three samples from 1-2 foot depth in Oakland Bay were measured for PCBs. Total PCBs were not detected in any subsurface sediment sample (see Appendix G). All detection limits were below the SMS criterion.

5.5.4 Chlorinated Pesticides

All samples from 1-2 foot depth within Shelton Harbor and three samples from 1-2 foot depth in Oakland Bay were measured for chlorinated pesticides. In general, low levels of chlorinated pesticides were found in subsurface sediments across Shelton Harbor and Oakland Bay. The most common compounds found were 4,4’-DDT or associated breakdown products (4,4’-DDD and 4,4’-DDE) and alpha-chlordane. Aldrin, dieldrin, and heptachlor were found in Shelton Harbor subsurface sediments, but not in Oakland Bay. The concentration of aldrin (19 µg/kg) and heptachlor (16 µg/kg) in subsurface sediment were more than twice the value in surface sediment at location SH-08. No LAET criteria (established only for DDT, DDD, and DDE) were exceeded.

5.5.5 Semivolatile Organic Compounds: PAHs, Phthalates, and Phenols

All samples from 1-2 foot depth within Shelton Harbor and three samples from 1-2 foot depth in Oakland Bay were measured for SVOCs. No detected values of SVOCs exceeded SMS criteria. The most common SVOCs detected in subsurface sediments were PAHs. Total LPAHs were detected in 72 percent of Shelton Harbor subsurface sediment samples and were not detected in Oakland Bay subsurface sediments samples. Total HPAHs were detected in 80 percent of Shelton Harbor subsurface sediment samples and two of the three Oakland Bay subsurface sediment samples (see Table 4-1).

In Shelton Harbor, total LPAH and HPAH concentrations were highest along the shoreline in the former pond saw area, along the southwest shoreline, and in the log rafting area south of the railway log dump, which corresponds to wood waste accumulation areas identified on Figure 5-2. In general, PAH concentrations decrease to the east, leaving the harbor.

Low-concentration total HPAHs were detected in two of the three Oakland Bay subsurface sediment samples, both of which were located along the southeastern shore of Oakland Bay (OB-18 and OB-19).

Several other SVOCs were detected at low levels in subsurface sediment samples, including one phthalate (BEHP), two phenols (4-methylphenol and phenol), and dibenzofuran. No other SMS SVOC compounds were detected above laboratory reporting limits in any subsurface sediment samples across the site.

BEHP was found in subsurface sediment samples only in the northern portion of Shelton Harbor (from station SH-04 extending east to SH-29 and north to SH-30).

4-Methylphenol was found only in subsurface samples from the southern portion of Shelton Harbor (Simpson property shoreline extending east to SH-14). Phenol was found in the middle of Shelton Harbor and at one location in Oakland Bay near Chapman Cove, in the log rafting lease area.

Dibenzofuran was detected in subsurface sediment at two locations, both of which are located along the southwest shoreline near upland discharge outfalls (SH-12 and SH-18).

5.5.6 Resin Acids and Guaiacols

Resin acids and guaiacols were measured in the 1-2 foot depth at 11 stations in Shelton Harbor and 3 stations in Oakland Bay. One or more resin acid compounds were detected in all subsurface wood waste sediment samples analyzed, with the exception of SH-26; no guaiacol compounds were detected in any samples. The most common resin acid compounds detected in subsurface sediment samples were abietic acid, dehydroabietic acid, isopimaric acid, and retene. Additionally, linolenic acid, neoabietic acid, oleic acid, palustric acid, pimaric acid, and sandaracopimaric acid were detected in Shelton Harbor subsurface sediment samples, but not in Oakland Bay subsurface sediment samples.

Figure 5-11.
Surface and subsurface collocated sample dioxin distribution, across the Oakland Bay study area.

Legend

● Historic emission stack

Dioxin (TEQ) (ng/kg)

☐	< 4
🟦	4 to 10
🟩	10 to 20
🟨	20 to 60
🟧	60 to 100
🟪	100 to 200
🟥	200 to 400
🟫	> 400
☒	No data

Collected Sample Depth

Surface sample (top 0.3 feet)
1-2 feet
2-3 feet

N

0 1,050 2,100 4,200 Feet

HERRERA
ENVIRONMENTAL CONSULTANTS

Aerial: USDA, 2006

Produced By: GIS (rdr)
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As with surface sediment samples, total resin acids are highest in the south and southwest portions of Shelton Harbor; the highest concentration found was 68,000 µg/kg at SH-21, located within a wood waste accumulation area on Figure 5-2. An elevated total resin acid value (21,000 µg/kg) is also present in the northern portion of Shelton Harbor (SH-27). In general, subsurface sediment results for total resin acids were higher than surface sediment results in both Shelton Harbor and Oakland Bay.

All five sampling stations exhibiting relatively high resin acid content (>3,500 µg/kg) had visible wood present, all five sampling stations with medium level resin acid content (1,500 to 3,500 µg/kg) had visible wood present, and one of three sampling stations exhibiting relatively low resin acid content (<1, 000 µg/kg) had visible wood present.

5.5.7 Tributyltins

TBTs were not detected in any of the three subsurface sediment samples where they were measured.

5.5.8 Metals

Metals were analyzed in the 1-2 foot depth sample at all stations in Shelton Harbor and 3 stations in Oakland Bay. Metals were detected at low levels in all samples across the study area; no values exceeded SMS criteria. In general, mean concentrations of metals in subsurface sediment samples were similar in Shelton Harbor and Oakland Bay. The highest concentration of metals was found in Shelton Harbor near the sawdust loading area (SH-11, SH-12, and SH-18).

5.5.9 Petroleum Hydrocarbons

Petroleum hydrocarbons were tested at two subsurface locations. Lube oil-range hydrocarbons were found at a concentration of 270 mg/kg in the subsurface sediment sample collected at station SH-02, located south of the vessel haul out (lube oil-range hydrocarbons were found in surface sediment only at SH-05). Petroleum hydrocarbons were not detected in the other subsurface sediment sample collected at station SH-01.

5.6 Bioassay Toxicity

Bioassay test results across the Oakland Bay study area are provided in Figure 5-12. SQS and CSL failures occurred throughout Shelton Harbor and Oakland Bay, both along the shoreline and across the entire water bodies. The only Hammersley Inlet failure occurred along the shoreline at Millers Point. A comparison of the combined toxicity test results (pass/fail inclusive of all four toxicity tests) with wood presence in surface samples is provided in Table 5-4; a detailed statistical evaluation for each test is provided in Section 7.4.

Table 5-4. Bioassay test results compared to visible wood presence in surface sediment across the Oakland Bay study area.

SMS Toxicity Test Result	Oakland Bay		Hammersley Inlet		Shelton Harbor		Study Area	
	Wood	No Wood	Wood	No Wood	Wood	No Wood	Wood	No Wood
Pass	2	4	1	4	6	8	9	16
Fail	2	9	0	1	11	2	13	12

SMS Sediment Management Standards

Toxicity test pass/fail results for samples collected in areas with high accumulation of wood waste were inconsistent (compare Figure 5-12 with Figures 5-1 and 5-2). Samples collected from the Shelton Creek and Goldsborough Creek alluvial fan area generally failed the larval acute test; however, two samples collected from the former sawmill#4 wood waste accumulation area passed all tests.

5.6.1 10-Day Amphipod

Only one location (OB-03) had a marginal (4 percent) exceedance for the amphipod toxicity test; all other toxicity tests at this location passed SMS criteria. Percent fines measured in the field by wet sieving was 54 percent, indicating that the toxicity analysis should be performed using *A. abdita* as the test organism (i.e., less than 60 percent fines). Later laboratory testing measured total fines for this sample as 70 percent. The failure may have resulted from improper test organism selection associated with the less accurate field measurement.

5.6.2 Larval Development

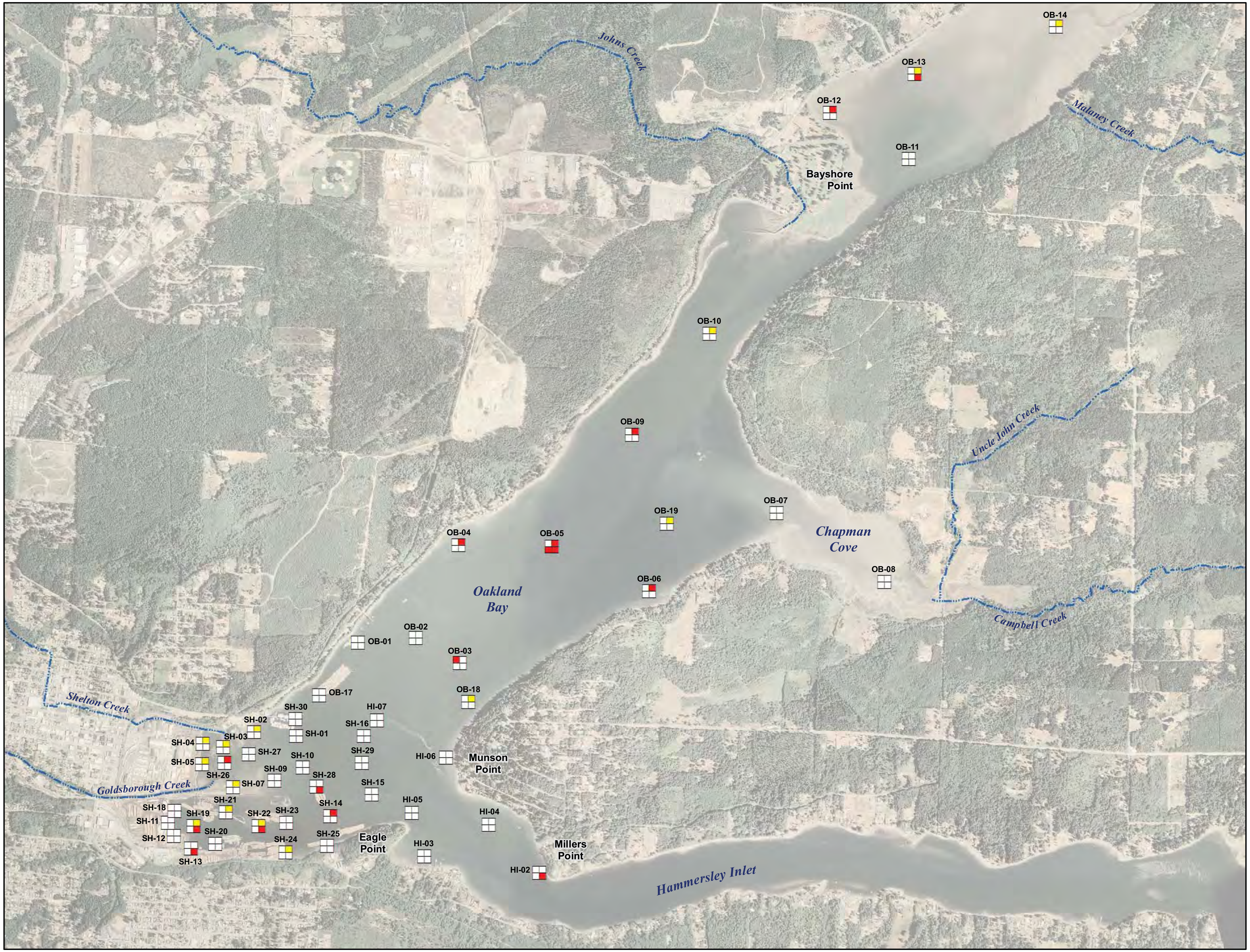
In Shelton Harbor, larval toxicity failures primarily occurred along the north and northwest shoreline (SH-02 through SH-07) and in the south, associated with areas of wood waste accumulation (Figure 5-2). Of the 11 larval toxicity failures in Shelton Harbor, 82 percent (nine locations) failed CSL criteria and 18 percent (two locations) failed SQS criteria.

In Oakland Bay, larval toxicity failures primarily occurred in the central and upper portions of the bay. Two failures also occurred along the eastern side of the bay, where logs have historically been rafted (OB-18 and OB-19). Of the 10 larval toxicity failures in Oakland Bay, 50 percent (five locations) failed CSL criteria and 50 percent (five locations) failed SQS criteria.

5.6.3 Juvenile Polychaete

Four locations in Shelton Harbor failed SQS criteria for juvenile polychaete toxicity. All failures (SH-13, SH-19, SH-22, and SH-28) were within 10 percent of the 70 percent criterion for mean individual growth rate. Only two locations (SH-19 and SH-22) had an additional toxicity test failure (larval toxicity).

Figure 5-12.
Bioassay test results across the Oakland Bay study area.



Legend

☐	Pass SMS criteria
🟨	Fail CSL criteria
🟥	Fail SQS criteria

Bioassay tests

Amphipod	Larval
Microtox	Polychaete

Note: Surface samples collected from top 0.3 feet.

N

0 1,050 2,100 4,200
Feet

HERRERA
ENVIRONMENTAL CONSULTANTS

Aerial: USDA, 2006

Produced By: GIS (rdr)
Project: K:\Projects\06-03386-007\Project\Result_Figures\Bioassay_results-11x17.mxd

Two locations (OB-05 and OB-13) in Oakland Bay failed SQS criteria for juvenile polychaete toxicity. Location OB-05 also failed for both larval development toxicity and Microtox testing; location OB-13 had one additional toxicity test failure (larval toxicity).

One location (HI-02) in Hammersley Inlet failed SQS criteria for juvenile polychaete toxicity. This sample is located along the shore, near Millers Point.

5.6.4 Microtox

One location (OB-05) failed SQS criteria for Microtox testing. This sample also failed SQS criteria for both larval and juvenile polychaete toxicity.

6.0 Fingerprinting Analysis of Sediment Data

Screening-level fingerprinting evaluations for TPH, PAH, and dioxin/furan sediment data were conducted to determine if they could be used to differentiate between potential contaminant sources. This was done by evaluating the Oakland Bay investigation data set for quantity and quality of data and then comparing the appropriate values with known source data. A technical memo was developed to justify the fingerprinting process for each contaminant type based on data usability (Appendix K).

For this investigation, concentrations of all analytes reported between the method detection limit (MDL) and practical quantitation limit (PQL [also known as reporting limit]) have all been annotated with a “J” qualifier (estimated concentration), indicating a high level of uncertainty in the quantitative value. Statistical evaluations of data whose uncertainties are “high” can lead to erroneous conclusions, especially if the sample populations being compared are limited in size or are highly censored (high percentages of non-detect data). To determine the usefulness of the analytical data for differentiating between possible sources of contaminants, only un-qualified data measured at concentrations at least three times above the practical quantitation limit were evaluated.

Petroleum hydrocarbons were rarely detected, and when detected, had concentrations close to detection limits. No petroleum data met the minimum requirement for additional evaluation. Based on the inherent limitations in TPH analyses and the highly censored nature of these data, conducting a detailed fingerprinting analysis was determined not be practicable.

PAH data from Oakland Bay and Hammersley Inlet also were highly censored (a large number of non-detect data), with only a single non-qualified positive result greater than three times the PQL. In Shelton Harbor, 82 percent of surface sediment and 84 percent of subsurface sediment PAH data were determined to be of relatively high quantitative uncertainty (Taylor 1987). Assuming that a minimum of five individual PAHs must be present in a sample at concentrations greater than three times the PQL for fingerprint analysis, then approximately one-sixth of the stations would have sufficient data at one or more depth intervals to evaluate relative ratios of individual PAH concentrations. Even if the data set is restricted to only Shelton Harbor, more than three-quarters of the stations failed to meet the minimum requirement of five individual PAHs with un-qualified concentrations more than three times the PQL. Based on the small amount of viable data, fingerprinting PAHs in Oakland Bay, Hammersley Inlet, or Shelton Harbor would not provide reliable results.

Enough dioxin/furan data from Oakland Bay, Hammersley Inlet, and Shelton Harbor with un-qualified values at concentrations at least three times the PQL were available for fingerprinting analysis.

6.1 Fingerprinting Analysis of Dioxins and Furans

Dioxins and furans come from many sources such as waste incineration, power/energy generation, minimally controlled and uncontrolled combustion, chemical manufacturing, and natural sources. Each source generates its own specific mixture and concentrations of congeners that in some cases can be used as a "fingerprint" for source identification in environment samples.

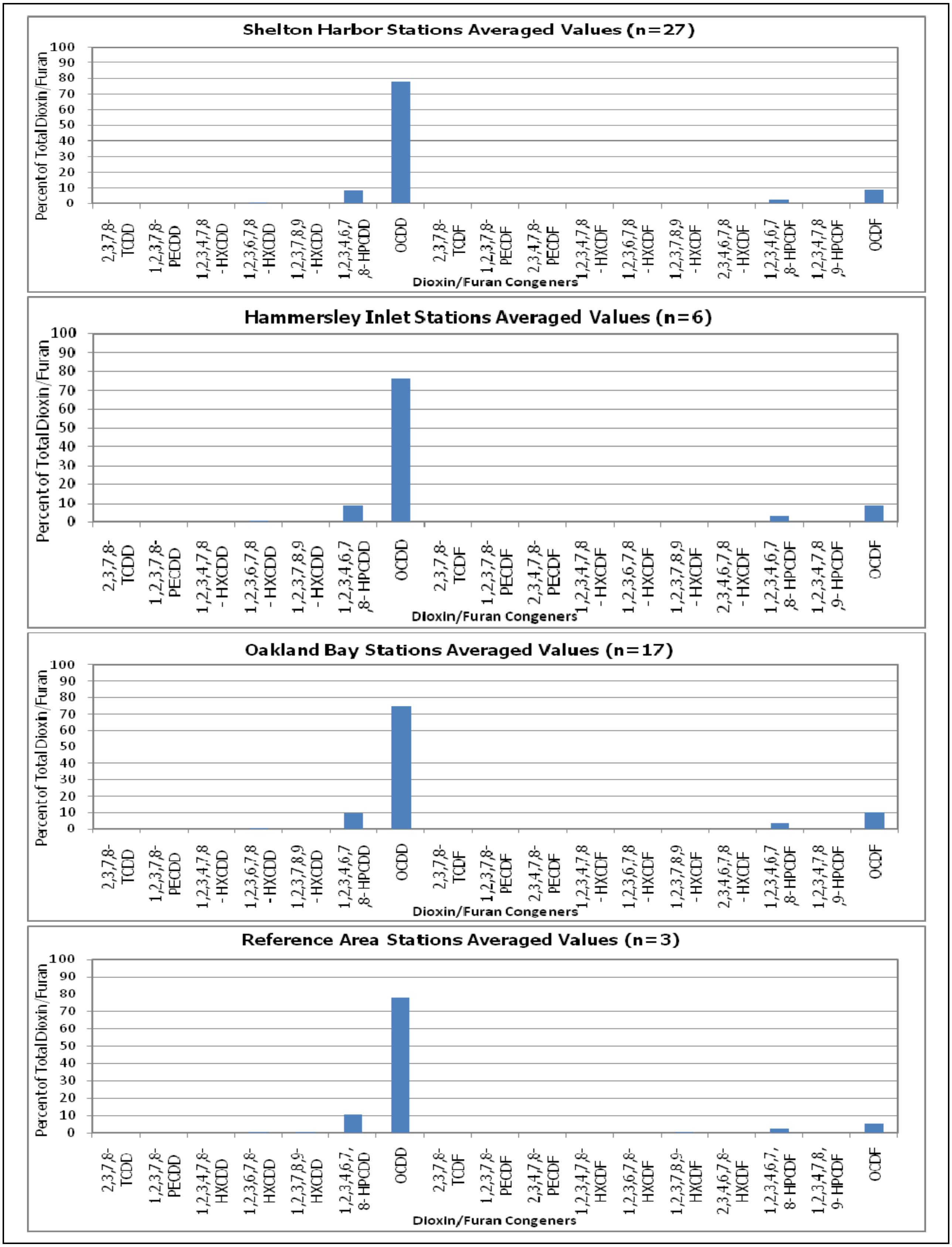
Dioxins and furans are families of related compounds with from 1 to 8 chlorine atoms located at various positions around a base carbon ring structure. Each unique compound is referred to as a congener. Congeners with the same number of chlorine atoms are referred to as homologues. There are 75 different dioxin congeners and 135 different furan congeners. Congeners vary significantly in their toxicity. Dioxin and furan congener source information has been used to generate visual profiles (bar graphs) in *An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for the Years 1987, 1995, and 2000* (USEPA 2006).

The bar graphs show the proportion of each congener (17 congeners in all) to the total mass of the dioxin and furan congeners. These visual profiles can be compared to profiles from environmental samples to identify possible dioxin and furan sources in the environment. In comparing the profiles, the evaluator looks for the presence of similar congeners (bars) that are also at approximately the same proportion (graph height). The more congeners found in the samples that match a source type, the better the fit. In some cases, there are multiple chemical sources, which create a mixture of dioxins and furans; this requires advanced statistical analysis to determine possible source types. In some cases, more than one USEPA source profile may match the environmental samples and additional sampling or further site investigations may be needed.

In addition to USEPA source identification, dioxin and furan profiles of environmental samples can be used to compare different site areas, other nearby sites, and background/reference areas. Statistical analysis of the values used to create the graphs is often used to determine if samples are from different sources or from the same source. In this section, the dioxin and furan profiles from Oakland Bay are compared by sub-area (Oakland Bay, Shelton Harbor, Hammersley Inlet, and reference stations); and are compared to data from Goose Lake, background dioxin/furan data from sub-basins within Puget Sound, and to selected profiles from the USEPA source inventory.

6.2 Proportional Distribution of Dioxins/Furans Congener Concentrations

The proportion that each dioxin/furan congener contributes to the total concentration of congeners across the study area and for each sub-basin is shown on Figure 6-1. The visual analysis of the graphs from each of the three sub-basins indicates that the source of dioxins and furans are consistent throughout the study area. Note that the profile for the reference area stations is quite similar as well, although concentrations in the reference samples were significantly lower than that found in the study area. Table 6-1 provides a breakdown of the primary dioxin/furan congeners found across the Oakland Bay study area and reference area



Shelton Harbor Stations Averaged Values (n=27)

Hammersley Inlet Stations Averaged Values (n=6)

Oakland Bay Stations Averaged Values (n=17)

Reference Area Stations Averaged Values (n=3)

Figure 6-1. **Relative percent of congeners (compared to total dioxin/furan congeners) from Shelton Harbor, Hammersley Inlet, Oakland Bay and Reference Area.**

samples based on the 53 samples collected. The remaining congeners represent less than 1 percent each of the total congener dioxin/furan mass.

Table 6-1. Primary dioxin/furan congeners found across the Oakland Bay study area.

Study Area	Congener	Mean Total Dioxin/Furan Congeners by Mass (%)
Hammersley Inlet	1,2,3,4,6,7,8-HpCDD	9.20
Oakland Bay		9.59
Shelton Harbor		8.35
Total Study Area		8.96
Hammersley Inlet	OCDD	76.4
Oakland Bay		74.8
Shelton Harbor		78.0
Total Study Area		76.7
Hammersley Inlet	1,2,3,4,6,7,8-HpCDF	3.20
Oakland Bay		3.60
Shelton Harbor		2.85
Total Study Area		3.12
Hammersley Inlet	OCDF	8.98
Oakland Bay		9.80
Shelton Harbor		9.05
Total Study Area		9.09

6.3 Comparison of Oakland Bay Study Sediment Dioxins/Furans Congener Data to Goose Lake Congener Data

Sulfite liquor waste from the Rayonier pulp and paper mill was discharged to Goose Lake from the early 1930s to the mid-1940s. A comparison of dioxin and furan congener data from Goose Lake and its associated drainage ravine and Oakland Bay was conducted to determine if similarities exist between the two profiles. Goose Lake dioxin/furan data were obtained from Ecology's Environmental Information Management (EIM) website.

The dioxin/furan congener proportional-distribution profiles of the Goose Lake dataset indicate greater variability than those of Oakland Bay, as determined by a comparison of coefficient of variation (CV); a greater CV indicates greater variability in the sample population. Specifically, the proportion of octachlorodibenzo-p-dioxin (OCDD) in sediment samples from Goose Lake has a mean percent value of 56.4, with a standard deviation of 17.8 (CV=0.32) compared to the entire set of Oakland Bay study samples, with a mean percent value of 76.7 and standard deviation of only 4.43 (CV=0.06). Figure 6-2a illustrates the variability in dioxin/furan congener

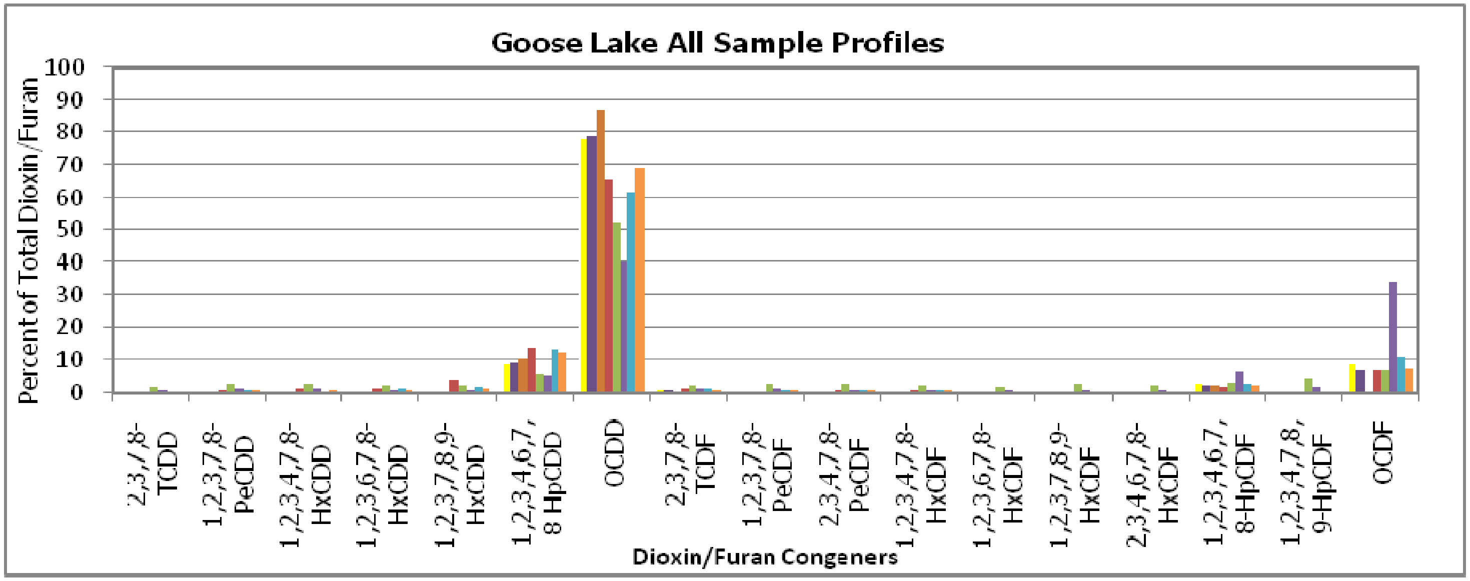


Figure 6-2a. Proportions of dioxin/furan congeners from *all* samples collected from Goose Lake data (n=8).

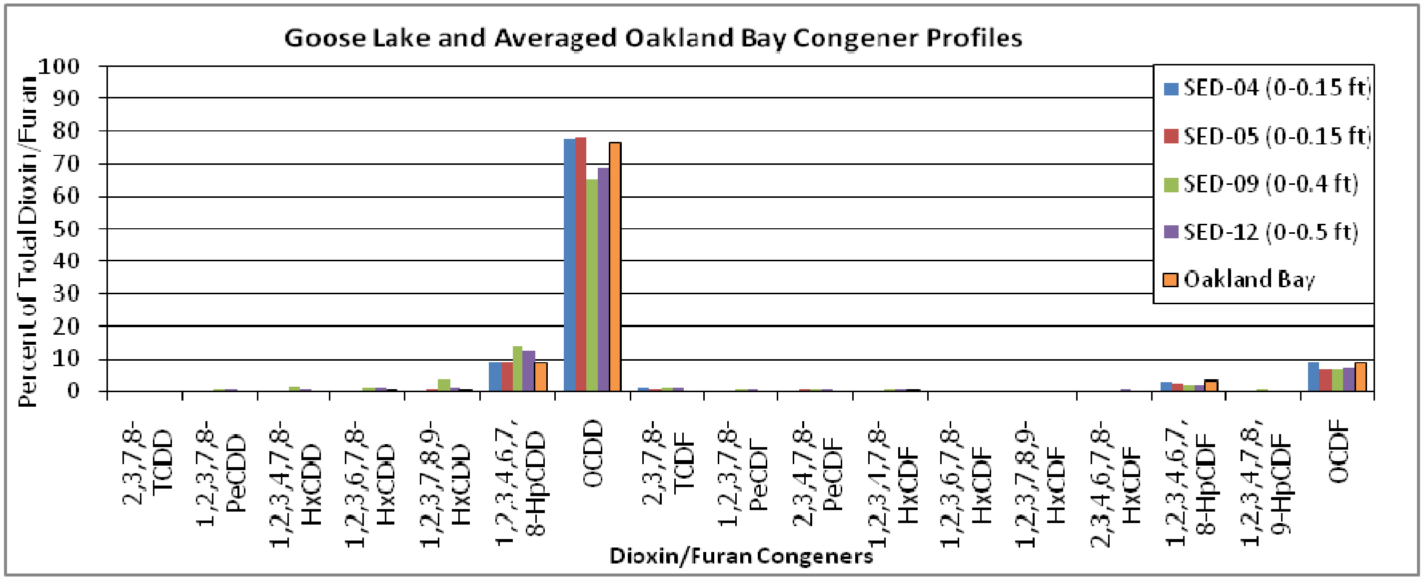


Figure 6-2b. Average proportions of dioxin/furan congeners in sediment from the Oakland Bay study area compared to four Goose Lake surface sediment samples having total congener concentrations greater than 150 parts per trillion dry weight.

proportional-distribution profiles among each of the eight sediment samples collected at Goose Lake. Surface sample results only are provided in Figure 6-2b, along with the average Oakland Bay profile. Table 6-2 presents Goose Lake sample results by location and depth. The subsurface samples, with lower dioxin/furan concentrations, introduce most of the variability to the Goose Lake dataset. The surface sediments exhibit congener profile patterns more similar to themselves and to those of Oakland Bay sediments than to the deeper Goose Lake sediments.

Table 6-2. Goose Lake dioxin/furan sample results.

Location	Depth (feet)	Sum of Congeners (ng/kg)
SED-04	0-0.15	407
SED-05	0-0.15	1,520
SED-08	0-0.15	134
SED-09	0-0.4	1,180
SED-10	0.5-2	6.28
SED-10	4-4.5	13.5
SED-11	0.75-1.25	95.1
SED-12	0-0.5	179

Shaded samples used in Figure 6-2b.

Historical use and sedimentation studies were not conducted for Goose Lake, so no historical perspective can be established for the surface and subsurface sediments tested. Sulfite liquor discharges to the lake occurred between the early 1930s and the mid 1940s. It is probable that dioxin associated with that source would be found beneath the surface, assuming that some sedimentation has occurred since the 1940s. The difference between the surface and subsurface profiles indicate either different source types or the impacts of degradation over time.

6.4 Comparison of Oakland Bay Sediment Study Dioxins/Furans Congener Data to Background Puget Sound Surface Sediment Congener Data

In July 2008, the USEPA conducted a comprehensive survey of Puget Sound surface sediments, including the 17 dioxin/furan congeners and eight dioxin/furan homologues tested in Oakland Bay, to establish area-wide background conditions (samples were collected from the OSV Bold). The greater Puget Sound region was divided into 14 sub-basins to determine how geography may affect the distribution of contaminants of concern, and if one sub-basin would be best suited as a reference area for future study comparisons. Sub-basins included:

Admiralty Inlet	Port Susan and Possession Sound
Carr Inlet	Samish Bay
Central Puget Sound	San Juan Islands
Dabob Bay	Saratoga Passage & Skagit Bay
Holmes Harbor	South Central Puget Sound
Hood Canal	South Puget Sound
North Central Puget Sound	Strait of Juan de Fuca

Descriptive statistics of the Oakland Bay and OSV Bold survey surface sediment dioxin/furan profiles are presented in Table 6-3.

Table 6-3. Comparison of Oakland Bay study and OSV Bold survey surface sediment dioxin/furan results.

Total Dioxin/Furan Congeners	Dioxin/Furan Concentration Oakland Harbor Study (ng/kg) 50 samples	Dioxin/Furan Concentration OSV Bold Survey (ng/kg) 75 samples
Mean	9,390.0	186.6
Median	7,010.2	127.2
Minimum	37.4	5.8 (U)
Maximum	83,240.1	2,130.3

Values not converted to TEQ

ng/kg – nanogram per kilogram

U – undetected, value to left indicates the detection limit.

Table 6-3 indicates clear differences between the two surveys in total concentrations of dioxins/furans, with Oakland Bay having higher values in all categories. However, the congener proportional-distribution found in Oakland Bay, Shelton Harbor, and Hammersley Inlet sub-basins are very similar to the Puget Sound sub-basins (Figures 6-3 a-c). As with the Oakland Bay Study, OCDD contributed the greatest amount to the sum total of dioxin/furan congeners (70 to 80 percent), with 1,2,3,4,6,7,8- heptachlorodibenzo-p-dioxin (HpCDD) at 10 percent and 1,2,3,4,6,7,8-heptachlorodibenzo-furan (HpCDF) and octochlorodibenzo-furan (OCDF) at roughly 5 percent or less. In addition, there appears to be a geographic trend in the Puget Sound profiles, with a slight reduction of percent contribution of 1,2,3,4,6,7,8-HpCDF and OCDF moving from the South Puget Sound/Carr Inlet sub-basin to South Central Puget Sound.

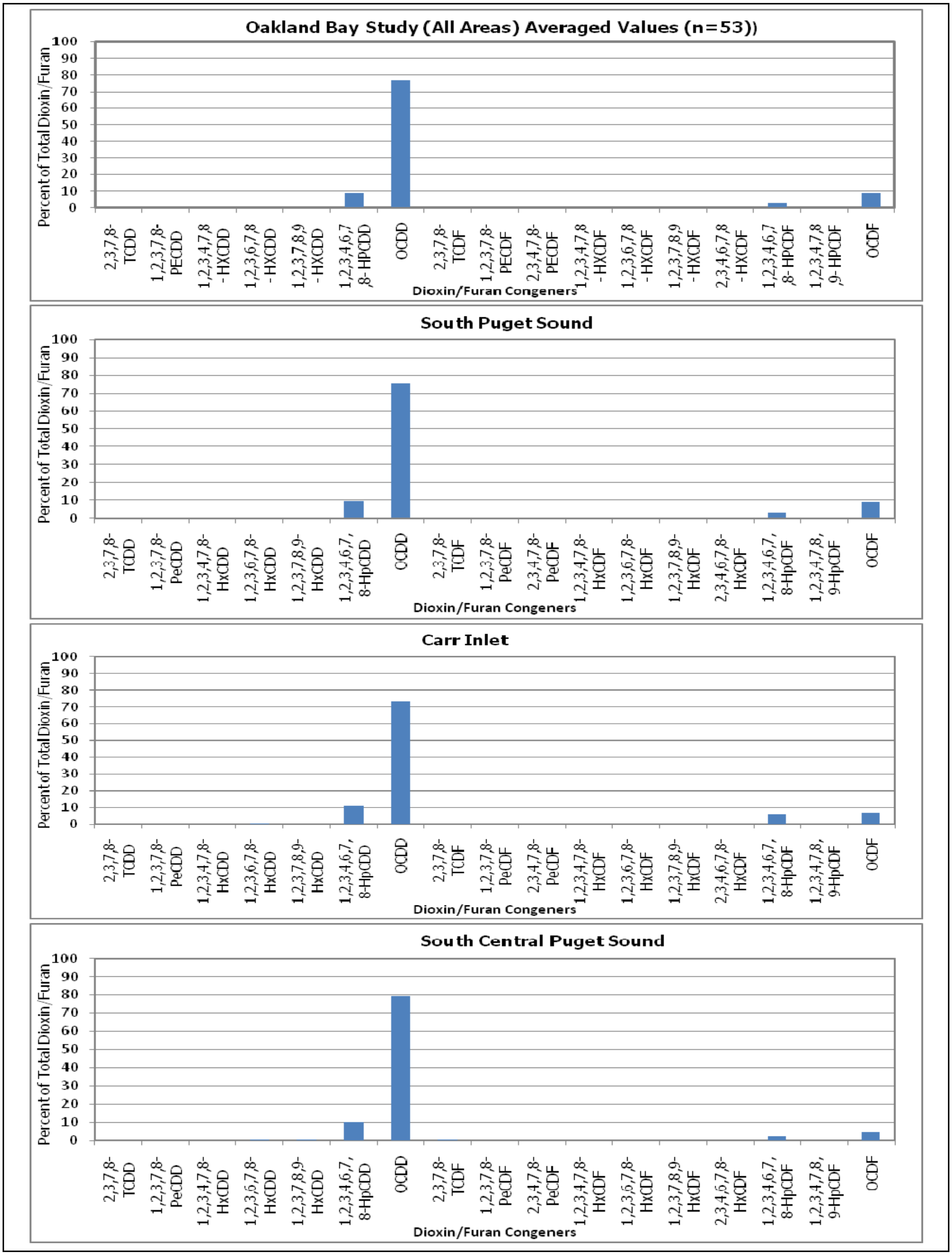
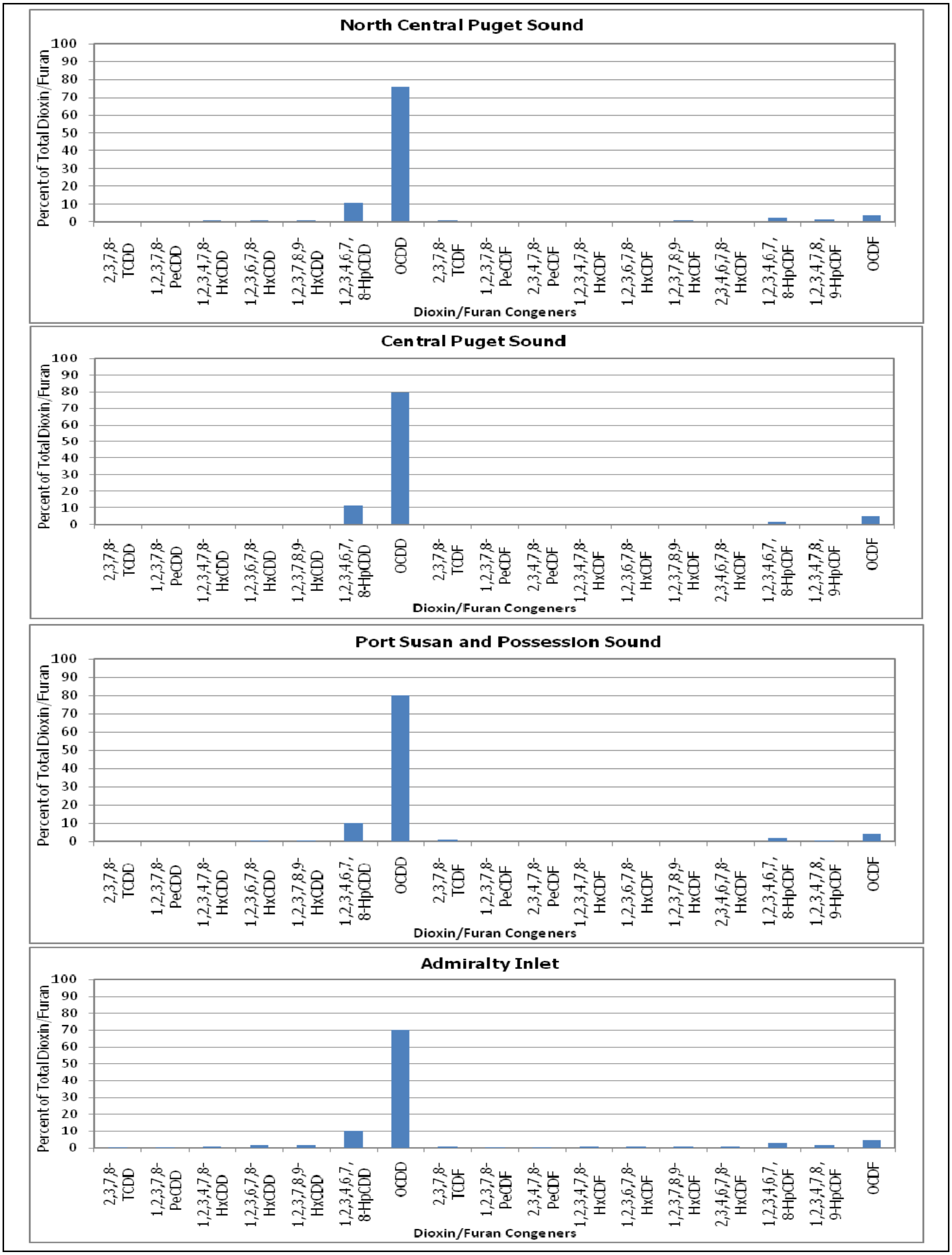


Figure 6-3a. Average proportional distribution profiles of congener concentrations to the total concentration of congeners from the OSV Bold survey and Oakland Bay study.



North Central Puget Sound

Central Puget Sound

Port Susan and Possession Sound

Admiralty Inlet

Figure 6-3b. Average proportional distribution profiles of congener concentrations to the total concentration of congeners from the OSV Bold survey.

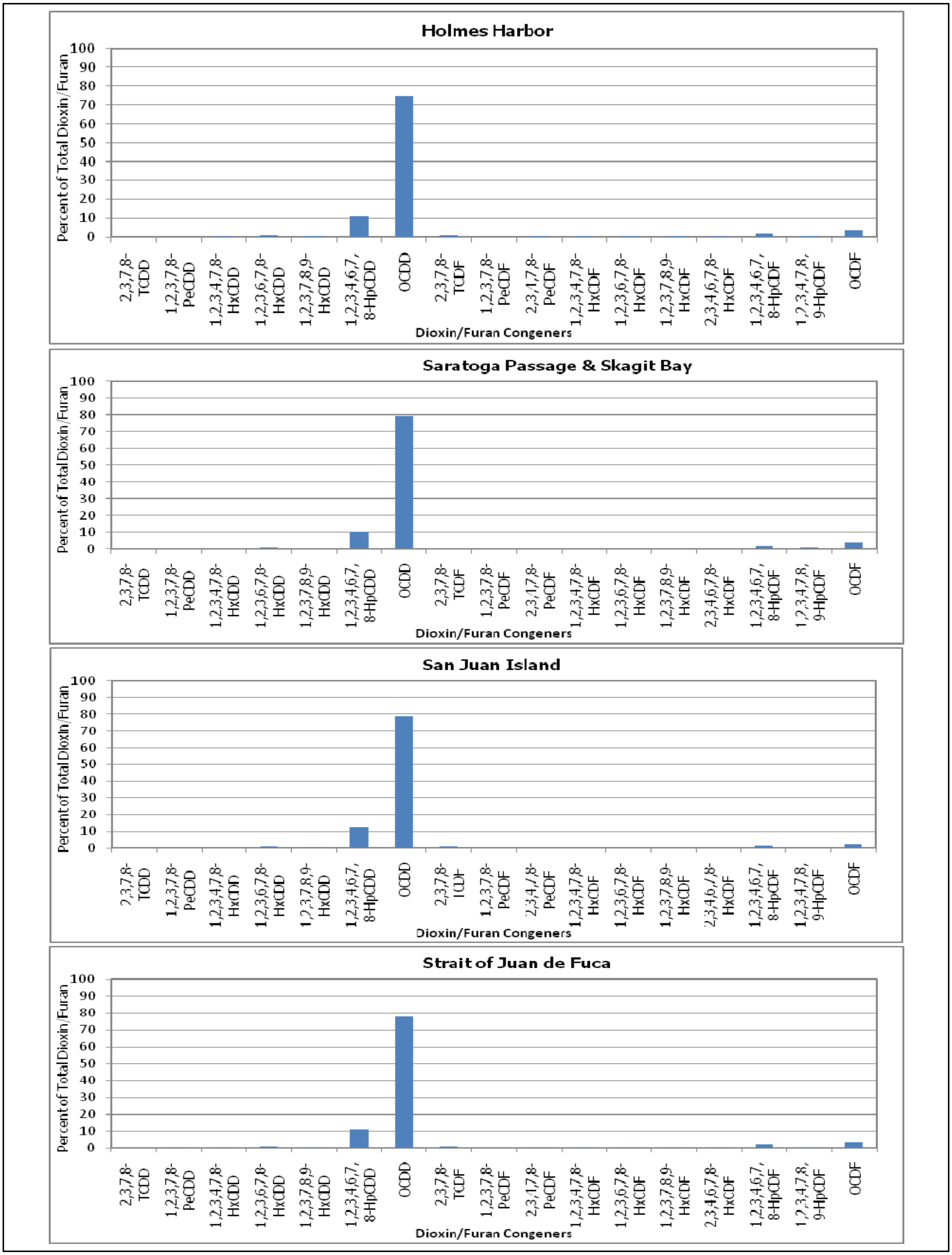


Figure 6-3c. Average proportional distribution profiles of congener concentrations to the total concentration of congeners from the OSV Bold survey.

6.5 Comparison of Congener Distributions in Oakland Bay Study Sediments to EPA Source Inventory Profile

Congener profiles from several sources in the United States were compiled by the USEPA National Center for Environment Assessment (USEPA 2006). Of the many source profiles compiled by the USEPA, 15 have been presented in Figures 6-4 a-d and listed in Table 6-4. The profiles illustrate the proportional distribution of 17 congeners from various natural and industrial sources. Figures 6-4 a-d depict the proportional-distribution congener profiles from the study area, along with source profiles from automotive emission, industrial wood burning, pulp paper process, forest fire, industrial oil-fired boiler, and pentachlorophenol sources. Several congener proportional-distribution profiles provided in Figure 6-4 a-d show general qualitative similarities between Oakland Bay area findings and source types. Congener profile data for other potential sources relevant to Oakland Bay, such as ash from burning of salt-laden wood, sulfite liquor waste, and sulfite liquor recovery boiler emissions, were not available in the EPA source inventory for comparison.

Table 6-4. USEPA source congener profiles presented in Figures 6-4 a-d.

USEPA Source Congener Profiles		
Diesel Fuel Truck	Electrostatic Precipitator Waste Ash	Pulp and Paper Mill Bleached Pulp (mid 1990s)
Unleaded Fueled Automobile	Forest Fires	Technical Grade PCP (1987)
Unleaded Fueled Automobile w/ Catalytic Convert	Black Liquor Recovery Boiler	Technical Grade PCP (1985-1987)
Industrial Wood Combustor	Pulp and Paper Mill Wastewater Effluent (mid 1990s)	PCP (NA from Closed Paper Mill in California)
Combustion of Bleach-Kraft Mill Sludge	Pulp and Paper Mill Wastewater Sludge (mid 1990s)	Oil-Fired Utility/Industrial Boilers

Five of the 15 USEPA-provided congener profiles were similar to those found in Oakland Bay sediments, including technical grade PCP (1987) (Figure 6-4d), black liquor recovery boiler stack emissions (Figure 6-4c), forest fires (Figure 6-4b), combustion of Bleach-Kraft mill sludge in wood residue boilers (Figure 6-4b), and unleaded fueled automobiles with catalytic converters (Figure 6-4a). PCP (1987) and black liquor recovery boiler emissions appear to match the closest, with all four primary congener compositions within two standard deviations of the mean found in Oakland Bay sediments. Black liquor is formed from the Kraft pulping process that converts wood into paper pulp (accounting for roughly 95 percent of the Oakland Bay study results). Table 6-5 provides dioxin/furan congener proportional-distribution profiles of the five source types (shaded values within two standard deviations of the Oakland Bay study means). PCP use and sulfite liquor (similar to black liquor) incineration are linked to activities within the study area (Herrera 2008a, Ecology 2000). Sulfite liquor also was burned in boilers from the mid-1940s to 1957.

Table 6-5. Comparison of possible source congener compositions with Oakland Bay study sediments.

Primary Dioxin and Furan Congeners in Oakland Bay	Oakland Bay Congener Composition Range (%) [a]	Technical Grade PCP (1987) (%)	Black Liquor Boiler Emissions (%)	Bleach-Kraft Mill Sludge (%)	Forest Fires (%)	Automobiles w/ Catalytic Converters (%)
1,2,3,4,6,7,8- HpCDD	6.22-11.7	9.5	7.6	12.3	17.0	6.5
OCDD	67.8-85.6	75.4	72.5	48.8	68.7	51.1
1,2,3,4,6,7,8- HpCDF	1.53-4.71	1.9	1.7	11.2	2.6	1.5
OCDF	3.89-14.29	13.1	7.9	7.7	1.0	13.2

[a] Range represents two standard deviations from the mean of Oakland Bay sediment samples (approximately 95 percent of all Oakland Bay samples fall within this range).

Shaded values are within two standard deviations of the Oakland Bay study mean value.

Although an USEPA source profile may match well with an environmental sample, the three PCP congener profiles in Figure 6-4d illustrate that matching source profiles with environmental samples is not exact; there is variability within source types – the three PCP-reference profiles have significant differences in proportional distributions. The PCP (NA from Closed Paper Mill in California) and the PCP (1985-87) profiles do not match well with the Oakland Bay profiles, whereas the PCP (1987) does match well. Before making any determination as to the exact source of dioxins and furans, additional sampling and analyses may be required to match specific sources.

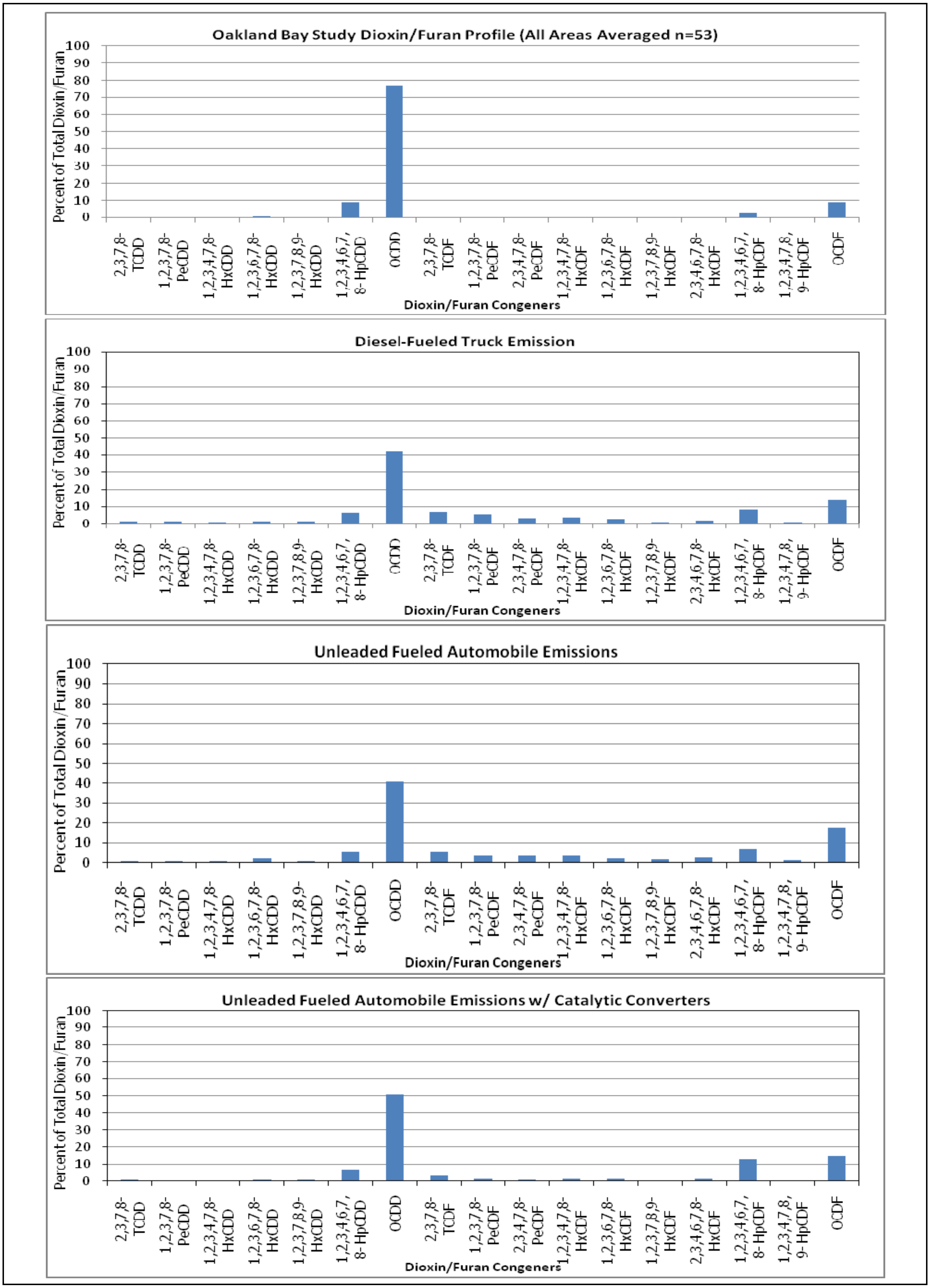


Figure 6-4a. Relative percent profiles of congener concentrations to the total concentration of congeners from various sources (USEPA 2006) and Oakland Bay study.

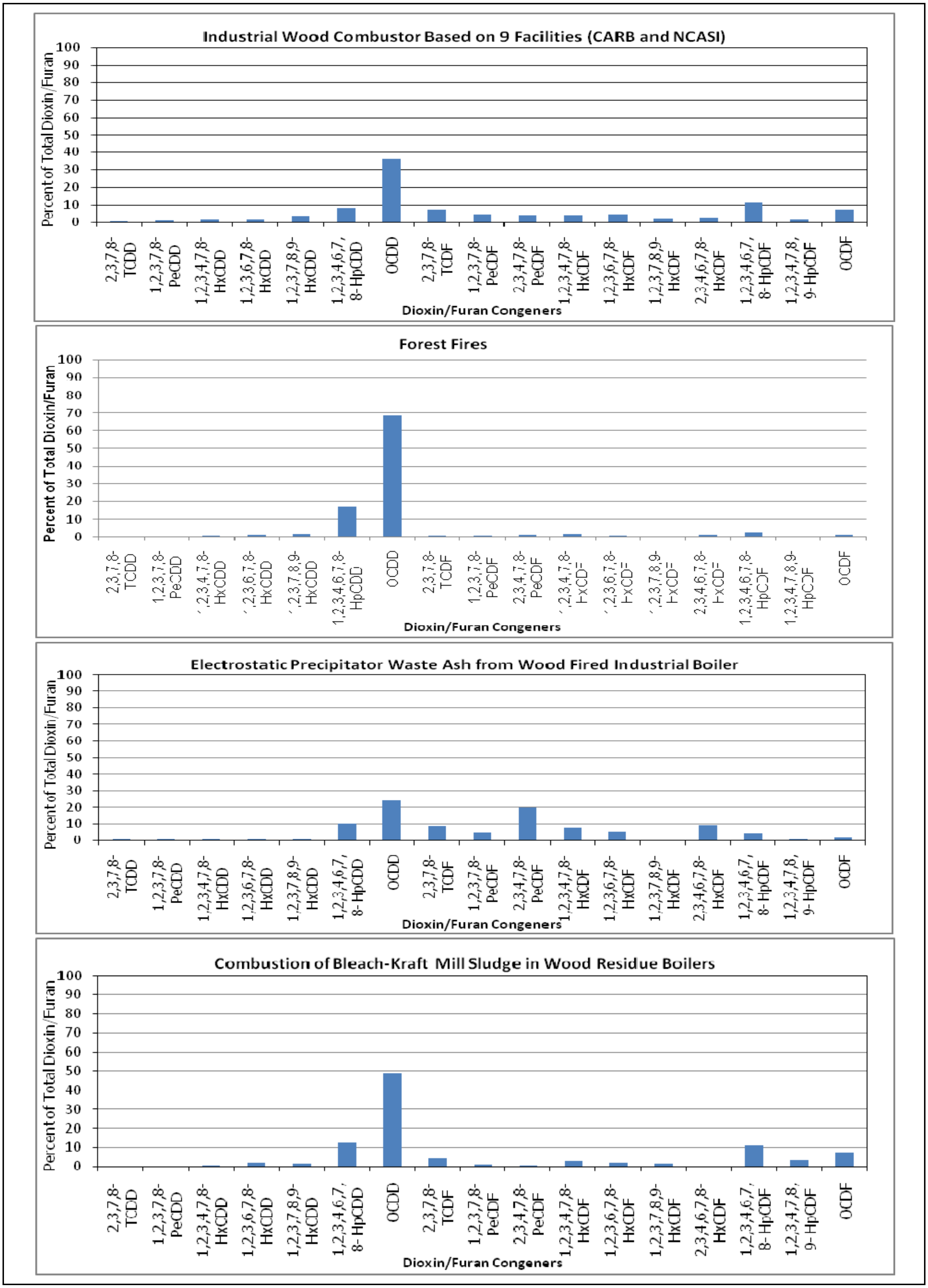


Figure 6-4b. **Relative percent profiles of congener concentrations to the total concentration of congeners from various sources (USEPA 2006).**

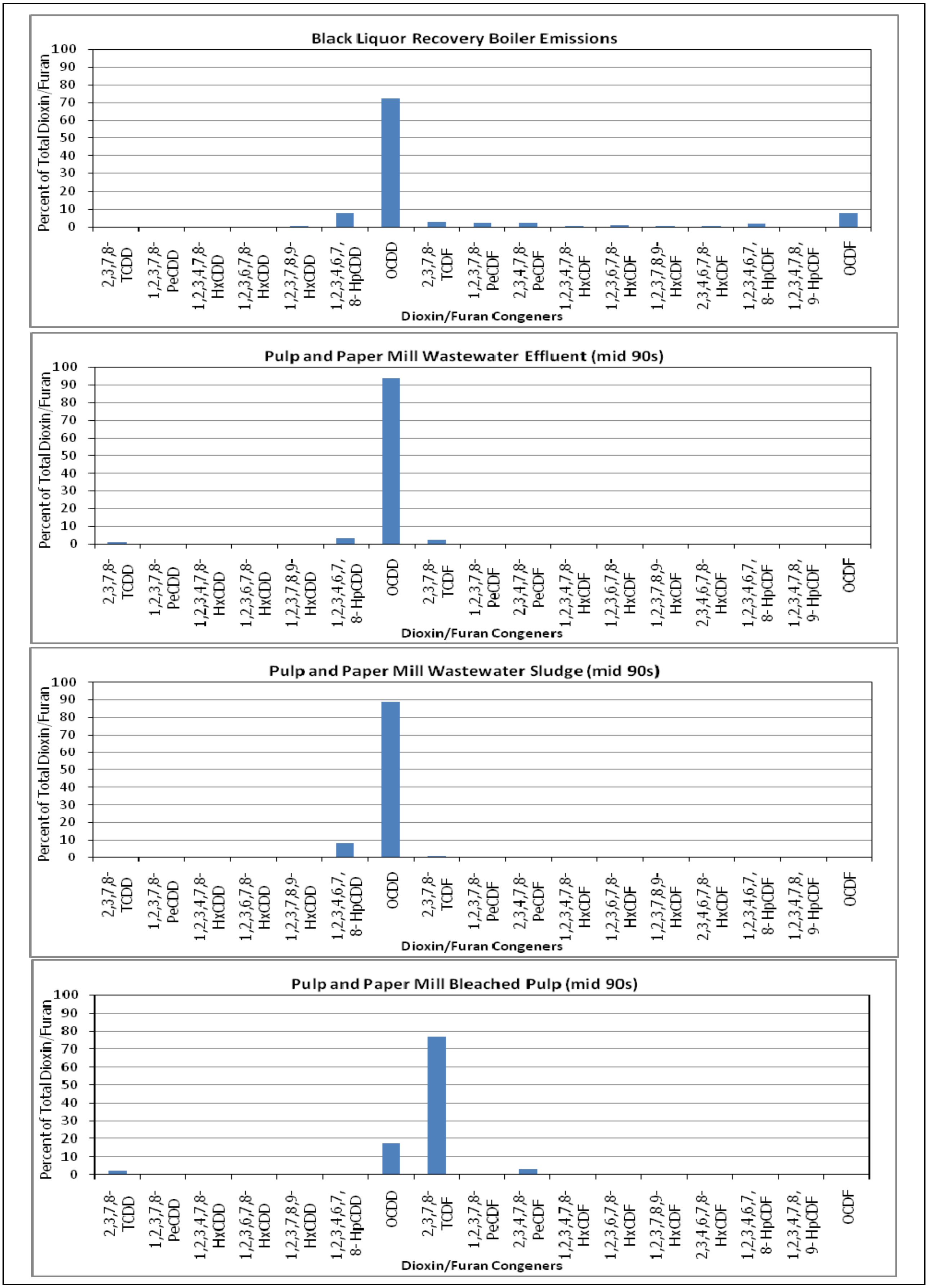


Figure 6-4c. Relative percent profiles of congener concentrations to the total concentration of congeners from various sources (USEPA2006).

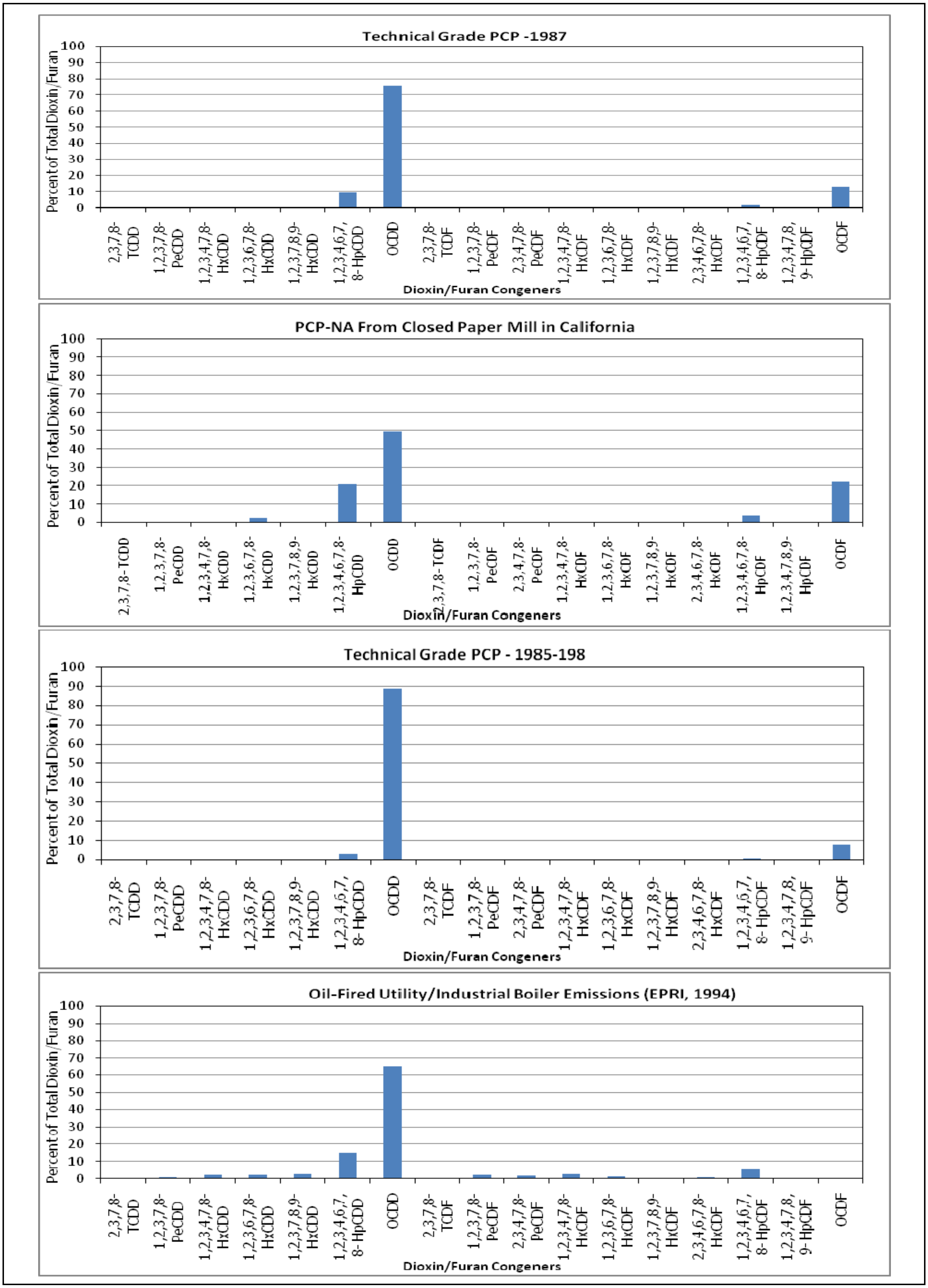


Figure 6-4d. Relative percent profiles of congener concentrations to the total concentration of congeners from various sources (USEPA 2006).

7.0 Sediment Quality Trends

This section summarizes sediment transport and accumulation across the Oakland Bay study area, the distribution of wood waste, and chemical and bioassay testing results. The chemical testing results also are compared to those of the 2000 Ecology Shelton Harbor investigation.

7.1 Sediment Transport and Accumulation

A sediment budget was developed by estimating accumulation rates determined from sediment core dating and a common sediment production model (Syvitski et al. 2005). The budget confirms that nearly all sediment deposited within the study area stays within the confines of greater Oakland Bay (including Shelton Harbor and Chapman Cove). While there is some transport of fine-grained sediment (silt and clay) from Shelton Harbor to central Oakland Bay, most sediment discharged to the bay remains close to where it first enters marine waters.

The pattern of circulation and sediment transport in Oakland Bay primarily results from tidal motion. First documented by Ecology (2004a), strong flows near the bed occur as marine water enters the study area from Hammersley Inlet on a rising or flood tide. Once high tide is reached and water begins to flow out of the study area, most flow leaves near the water surface. The strong bottom flows associated with flood tides are highly constrained within the narrow inlet bottom, preventing deposition in this area. The sediment accumulation that does occur in Hammersley Inlet and at the transition into Oakland Bay generally consists of coarse-grained material derived from eroded areas along Hammersley Inlet and Puget Sound shorelines; these volumes are small with respect to creek input to the bay. The strong bottom flow during flood tides pushes some sediment into Shelton Harbor and along the northern shore of Oakland Bay. Sediment transport is flood-dominated along the seabed; the ebb tide is dominated by flow at the surface, containing relatively small amounts of fine grain sediment. As such, very little sediment moves out of the system.

There are several consequences of this sediment transport relative to the pattern of COPCs found in the study area. Because sediment in Hammersley Inlet is either non-existent or derived from erosion input from the east, the seabed accumulates little chemical input from Shelton Harbor and greater Oakland Bay. The Oakland Bay system primarily receives sediment derived from Shelton Harbor and, to a lesser extent, Oakland Bay creeks. It can be assumed that COPCs found in Oakland Bay that are transported with sediment likely originate in Shelton Harbor (since no contaminants were identified at any of the Oakland Bay creeks). However, this study did not find evidence that significant concentrations of industrial COPCs, other than dioxins, exist in either the harbor or bay (COPCs associated with wood waste were found across both locations).

Dioxins were analyzed in multiple core sections at five locations across Oakland Bay (separate from Shelton Harbor). At all five stations, relatively higher dioxin concentrations were found in the 1-2 foot core section than in the surface grab sample (Figure 5-11 and Appendix G). This vertical distribution indicates that dioxin input has diminished over the last 30 to 60 years (based on the deposition rate range of 0.25 to 0.50 cm/yr [0.1 to 0.2 in/year] estimated for the bay). This corresponds to the time period when sulfite liquor waste and hog fuel burning was discontinued in the late 1950s and a salt-free wood burning power plant was installed by Simpson in 1986 (Herrera 2008a).

Sediment accumulation rates are variable, with faster accumulation occurring near the creek outlets, resulting in thicker depositional blankets in these areas. Higher dioxin concentration with depth can also be seen at SH-04 and SH-10, adjacent to Shelton and Goldsborough Creek discharges into the harbor. Cores collected at other locations in the harbor that do not indicate the same concentration profile may reflect near-surface sediment disturbances or more recent localized inputs.

7.2 Wood Waste Distribution

The pattern of sediment transport across the study area has resulted in accumulation of wood waste according to two primary modes: low concentrations spread across deeper portions of Oakland Bay by tidal flows near the sediment bed, and significant accumulations (greater than 20 percent by volume) near historical and current log rafting and wood processing activities. These distributions are illustrated in Figures 5-1 and 5-2. The general distribution of low concentration wood across the main portion of the study area is intermixed with the recent depositional layer, defined by the geophysical surveys (refer to Section 5.2.3 for an interpretive explanation regarding definition of the wood-containing sediment layer).

Wood waste observed in the cores has primarily originated from wood processing and rafting activities in Shelton Harbor and other isolated milling and rafting areas. The shedding of bark and chips associated with rafting has contributed to wood waste at low concentrations across the entire study area, including the northern end of Oakland Bay. Current log rafting and mill activity continue to be sources of wood waste.

- **Bark**: Wood waste was most prevalent as bark, found at 70 percent of sampling stations. The primary source of bark has likely been from log rafts historically stored across much of Shelton Harbor and the perimeter of Oakland Bay. The majority of bark was found in Shelton Harbor, where logs were delivered to the water by train and tugboat. Concentrated log handling activities along the shoreline where logs have been transferred in and out of storage have resulted in the largest accumulations of bark.

- **Chips**: Wood waste was found as chips at 26 percent of the sampling stations, primarily in Shelton Harbor, and mostly with less than 5 percent wood present. The primary source of chips is likely from wood processing operations.

- **Fibers**: Wood waste was found as fibers at 23 percent of the sampling stations, primarily in Shelton Harbor and mostly with less than 5 percent wood present. The primary source of fibers is likely from wood processing operations. Fibers were likely discharged as part of the sulfite liquor waste associated with historical paper production (which ended in the late 1950s) and from fiberboard manufacturing (conducted from the 1940s to 1974). The presence of fibers appears to be restricted to Shelton Harbor and, to a limited extent, along the southern shore of lower Oakland Bay.

- **Sawdust**: Wood waste was found as sawdust at 6 percent of the sampling stations. Sawdust was found at two Shelton Harbor locations and one Oakland Bay location, each with significant accumulations. The primary source of sawdust is likely from wood milling operations located at the west end of Shelton Harbor and at the head of Oakland Bay.

Most of the wood mass exists in sediment as a widespread, low-concentration deposit situated in the recently deposited marine bed surface associated with the onset of wood industry operations. Wood waste is often covered with a thin layer of cleaner sediment that has accumulated after the largest wood-waste-producing activities have stopped on a local basis. This is particularly true for wood deposited in the deeper sediments of Oakland Bay. The persistence of both significant wood accumulation on a local basis and the low-concentrations seen across both Shelton Harbor and Oakland Bay, support indications that the wood waste, like sediment, is relatively immobile.

Areas of concentrated wood waste are present within Shelton Harbor (Figure 4-3) and at one location in Oakland Bay. Areas of significant wood waste accumulation in Shelton Harbor include:

- The pond saw area (primarily sawdust at least 6.7 feet deep)
- The railway log dump to the south of the channelized mouth of Goldsborough Creek (fibers, chips, and bark 5 or more feet deep)
- Former sawmill #4 (primarily fibers and sawdust at least 10.5 feet deep)

The one area of significant wood waste accumulation in Oakland Bay was near the head of the bay, represented by core OB-12 (primarily sawdust at least 9.5 feet deep). The source of the Oakland Bay deposit is unknown, but may be an historical sawmill.

Figures 5-3 and 5-4 depict estimated wood waste present across the study area based on geophysical results and core sample descriptions. The figures denote thickness of material found above the predevelopment surface in areas where wood waste is known to occur from geomorphic evidence and core observations (it excludes the head of the bay not sampled as part of the geophysical survey, Hammersley Inlet where no sediment accumulation was found, and creek delta portions of Shelton Harbor that are covered with large-grain material). A total of 335,000 cubic yards (256,000 cubic meters) of wood waste was estimated to exist in the surveyed area, based on the volumetric content of the mapped recent deposition deposit and average visible wood waste concentrations obtained from the cores. Of this estimated total, approximately 240,000 cubic yards (183,500 cubic meters), or 72 percent of it, resides at low concentrations across the majority of Oakland Bay and Shelton Harbor. Approximately 95,000 cubic yards (73,000 cubic meters), or 28 percent, was estimated in the concentrated wood deposits (not including the area identified at the head of the bay). These numbers are rough estimates based on limited data, indicating the general distribution of wood waste across the entire study area.

7.3 Dioxins and Furans

Fifty surface sediment and 14 subsurface sediment samples across Shelton Harbor, Oakland Bay, and Hammersley Inlet were analyzed for seventeen dioxin/furan congeners and eight dioxin/furan homologues. Dioxins/furans were found in every sample, at concentrations ranging from 1 to 902 ng/kg TEQ. The five highest concentrations (180 to 902 ng/kg TEQ) were found at widely-spread subsurface locations along and near the western Shelton Harbor shoreline, within the Goldsborough Creek delta, and along the Oakland Bay shoreline south of Chapman Cove. The five samples collected from Hammersley Inlet were among the lowest dioxin/furan concentrations (1.77 to 9.74 ng/kg TEQ); flows through the central deep portion of Hammersley Inlet as it extends into Oakland Bay do not allow for a buildup of sediment and samples were collected along the fringes of the channel. The lowest dioxin TEQ concentrations were found in the three reference area samples (0.245 to 0.692 ng/kg TEQ).

Dioxins/furans were identified in surface sediment at all 50 locations sampled, ranging from 1 to 175 ng/kg TEQ. The five highest concentrations, represented as pink and orange in Figure 5-10, were found along the western edge of Shelton Harbor. Aside from the contrast of higher levels in Shelton Harbor and lower levels in Oakland Bay, no clear concentration gradient within the bay is apparent – concentrations among the Oakland Bay samples is relatively consistent. This suggests a generalized, widespread source to bay sediments, such as aerial deposition or a well mixed plume carried by water. Burning of waste material known to produce dioxins/furans occurred historically at five known locations near the southern shoreline of Shelton Harbor (Herrera, 2008a). Historical discharges of sulfite liquor waste and pulp mill process wastewater to Shelton Harbor and Hammersley Inlet may have contributed to dioxin/furan presence in bay sediments; however, probably not to surface sediments, based on the time of discharge and sedimentation that has occurred since. Discharge of slurries from the hog fuel boiler air pollution control system to the municipal wastewater treatment plant during the late 1970s – early 1980s may explain some dioxin found closer to the surface. The continued presence of dioxin in surface sediments indicates that there is either a continuing source of dioxin, or that mixing of deeper with shallower sediments has occurred through human or natural processes.

Subsurface sediment was sampled at 12 stations in Shelton Harbor and Oakland Bay, based on relatively high concentrations found in surface samples analyzed first (Figure 5-11). Samples were analyzed from either the 1-2 foot or 2-3 foot core sections to evaluate the effects of sediment accumulation over the last 60 years (samples were collected from both 1-2 and 2-3 foot core sections at two locations in Shelton Harbor along the western shore). The full depth of the sediments containing elevated dioxin was not identified. Higher dioxin/furan concentrations found at depth at nine of the 12 stations sampled indicates that burying of this sediment has taken place since the time of higher dioxin inputs, either by natural sedimentation or mixing associated with human activities. The 2-3 foot interval within Shelton Harbor (at estimated 1 cm/yr accumulation rate) can be roughly interpreted to represent the years 1920 – 1950. It is likely that dioxins/furans have been disbursed over a long period of time, through aerial and fluvial processes. Once incorporated into sediments, there has been little movement across or out of the Oakland Bay system.

Dioxin/furan fingerprint analysis compared congener proportional-distribution profiles for specific sources compiled by USEPA to Oakland Bay study profiles. Similar profiles were identified for PCP, black liquor boiler recovery emissions, automobiles with catalytic converters, forest fires, and combustion of bleach-Kraft mill sludge (certain PCP and black liquor boiler recovery stack emissions most closely match Oakland Bay sediment profiles). Congener profile data for other potential sources relevant to Oakland bay, such as burning of salt-laden wood, sulfite liquor waste, and sulfite liquor recovery boiler emissions, were not available for comparison. The dioxin/furan congeners found in Oakland Bay sediment appear similar to those found throughout Puget Sound. Goose Lake, known to have received Rayonier pulp and paper mill sulfite waste liquor, had dioxin/furan congener proportional-distribution profiles in surface sediments similar to the Oakland Bay study samples. Dioxin and furan congener compositions in deeper sediments did not match Oakland Bay as closely as the surface sediments. It appears that older dioxin/furan inputs to the lake were different than more recent inputs (e.g., older sulfite liquor waste discharged as a liquid versus more recent aerial deposition associated with combustion processes).

7.4 Relationship between Sediment Toxicity Tests and Chemical and Conventional Sediment Parameters

This section compares surface sediment chemistry results with results from the four separate sediment toxicity tests. The analysis was limited to analytes detected in more than 15 percent of collected samples, because the utility of statistical analysis is greatly reduced if a majority of the sample population is at or below detection limits. The analytes used in this analysis were:

- Wood content (visual)
- Percent fines
- TVS
- Ammonia
- Sulfides
- TOC
- Antimony
- Arsenic
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Nickel
- Silver

- Zinc
- Total LPAHs
- Total HPAHs
- Resin acids
- Dioxins/furans

In this study, relationships between sediment chemistry/physical properties and sediment toxicity were investigated using correlation analyses and hypothesis testing. The correlation analyses were used to screen the data and identify any strong relationships between toxicity and sediment chemistry. The Pearson's r correlation coefficient was initially considered for use in these analyses; however, the primary drawback to Pearson's r is that it assumes that the relationship between toxicity and sediment chemistry is linear. In this study, it is likely that varying pollutant concentration will not have an effect on toxicity until a certain threshold is achieved; consequently, a linear fit will not model the relationship well. A second drawback of the Pearson's r correlation coefficient is that it assumes that both the toxicity and sediment chemistry data follow a normal distribution (evenly distributed about the average value) (Helsel and Hirsch 1992). This assumption was determined not to be consistently true, based on results of a Kolmogorov-Smironov test for normality.

As a result of these considerations, the Kendall's Tau (τ) correlation coefficient was used instead of the Pearson's r. The Kendall's τ correlation coefficient offers the following specific advantages given the characteristics of the data in this study:

- It measures the strength of all monotonic relationships (e.g., linear, exponential, etc.) between variables, as opposed to just linear relationships.
- No assumptions are required regarding distribution of the data.
- It can be used with censored data having non-detect values.
- It is resistant to the effects of outliers.

The results from the analyses with Kendall's τ correlation coefficients are presented in Tables 7-1 and 7-2, which provide τ values measuring correlations between toxicity and chemical and physical parameter results (graphs of all the correlations are presented in Appendix L). A τ of +1 indicates a perfect positive relationship between the two variables, a τ of -1 indicates a perfect negative relationship, while a τ of 0 indicates no relationship between the variables. **Positive τ values for the amphipod test and negative τ values for all other toxicity tests indicate increasing toxicity with increasing concentration – this is because the amphipod test measures mortality and the other three tests measure survivorship.**

Table 7-1 indicates that amphipod test results indicated no significant correlation between mortality and most constituent concentrations; however, mortality results were negatively correlated with percent fines, antimony, silver, and dioxins/furans. In other words, as these concentrations increased, amphipod mortality decreased. This negative correlation cannot be

Table 7-1. Kendall's Tau (τ) correlation matrix of sediment toxicity and chemistry from all Oakland Bay study monitoring stations.

	Amphipod	Microtox	Larval	Polychaete	Resin Acids	TVS	Wood Content (visual)	Percent Fines	Ammonia	Sulfide	TOC	Antimony	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc	Total LPAHs	Total HPAHs	Dioxins / Furans
Amphipod	1.00	**0.29**	0.04	-0.06	-0.04	-0.02	-0.09	**-0.30**	-0.06	-0.07	-0.13	**-0.20**	-0.03	-0.11	-0.11	-0.13	-0.15	-0.12	-0.08	**-0.23**	-0.14	0.04	0.16	**-0.22**
Microtox		1.00	0.09	0.02	0.06	0.01	0.03	**-0.23**	0.00	-0.03	-0.16	-0.16	0.01	-0.07	-0.18	-0.18	-0.15	-0.14	-0.05	**-0.21**	-0.16	0.09	**0.23**	**-0.21**
Larval			1.00	0.09	-0.31	**-0.26**	**-0.38**	**-0.41**	**-0.30**	**-0.30**	**-0.44**	**-0.30**	**-0.29**	**-0.27**	**-0.33**	**-0.35**	**-0.30**	**-0.28**	**-0.26**	**-0.39**	**-0.31**	**0.39**	0.05	**-0.36**
Polychaete				1.00	-0.08	0.11	-0.28	-0.07	-0.15	-0.04	-0.09	-0.05	-0.04	0.01	-0.12	-0.09	0.00	0.00	-0.14	-0.08	-0.04	0.12	0.07	-0.02
Resin acids					1.00	**0.66**	**0.54**	0.11	0.27	0.08	**0.51**	0.25	0.36	0.30	0.17	0.15	0.25	0.35	0.08	0.24	0.22	-0.16	0.31	0.33
TVS						1.00	**0.46**	0.14	**0.22**	**0.20**	**0.39**	**0.31**	**0.29**	**0.31**	**0.30**	**0.37**	**0.27**	**0.33**	**0.24**	**0.25**	**0.30**	-0.07	**0.31**	**0.27**
Wood Content (visual)							1.00	**0.45**	**0.51**	**0.42**	**0.78**	**0.67**	**0.61**	**0.56**	**0.46**	**0.56**	**0.58**	**0.62**	**0.38**	**0.59**	**0.56**	-0.31	0.22	**0.70**
Percent Fines								1.00	**0.34**	**0.52**	**0.54**	**0.59**	**0.46**	**0.53**	**0.57**	**0.54**	**0.61**	**0.48**	**0.46**	**0.75**	**0.63**	**-0.38**	-0.15	**0.63**
Ammonia									1.00	**0.34**	**0.41**	**0.42**	**0.40**	**0.43**	**0.36**	**0.34**	**0.35**	**0.35**	**0.32**	**0.41**	**0.44**	**-0.25**	0.10	**0.32**
Sulfide										1.00	**0.52**	**0.45**	**0.47**	**0.51**	**0.37**	**0.40**	**0.44**	**0.40**	**0.33**	**0.50**	**0.48**	**-0.42**	-0.08	**0.45**
TOC											1.00	**0.59**	**0.49**	**0.59**	**0.47**	**0.57**	**0.56**	**0.52**	**0.35**	**0.59**	**0.58**	**-0.48**	0.03	**0.60**
Antimony												1.00	**0.66**	**0.70**	**0.62**	**0.67**	**0.78**	**0.69**	**0.53**	**0.77**	**0.78**	**-0.23**	0.13	**0.65**
Arsenic													1.00	**0.69**	**0.53**	**0.49**	**0.64**	**0.60**	**0.49**	**0.61**	**0.68**	**-0.22**	0.14	**0.55**
Cadmium														1.00	**0.55**	**0.60**	**0.73**	**0.70**	**0.51**	**0.68**	**0.78**	**-0.31**	0.10	**0.59**
Chromium															1.00	**0.80**	**0.66**	**0.57**	**0.79**	**0.66**	**0.75**	**-0.27**	0.09	**0.53**
Copper																1.00	**0.69**	**0.61**	**0.69**	**0.66**	**0.74**	**-0.26**	0.18	**0.57**
Lead																	1.00	**0.72**	**0.55**	**0.78**	**0.84**	**-0.27**	0.11	**0.72**
Mercury																		1.00	**0.48**	**0.65**	**0.74**	**-0.23**	0.17	**0.67**
Nickel																			1.00	**0.55**	**0.65**	**-0.20**	0.12	**0.39**
Silver																				1.00	**0.80**	**-0.32**	0.02	**0.73**
Zinc																					1.00	**-0.28**	0.11	**0.65**
Total LPAHs																						1.00	**0.39**	**-0.26**
Total HPAHs																							1.00	0.09
Dioxins / Furans																								1.00

Bold values indicate significant relationships (α=0.05); values above 0.5 or below -0.5 indicate a strong linear relationship.

PAH data were OC-normalized.

τ values below and above the diagonal are mirror images; only one dataset is shown to make the table easier to read.

Table 7-2. Kendall's Tau (τ) correlation matrix of sediment toxicity and chemistry for Shelton Harbor monitoring stations.

	Amphipod	Microtox	Larval	Polychaete	Resin acids	TVS	Wood Content (visual)	Percent Fines	Ammonia	Sulfide	TOC	Antimony	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc	Total LPAHs	Total HPAHs	Dioxins / Furans
Amphipod	1.00	**0.34**	-0.15	-0.14	-0.12	-0.04	-0.09	-0.27	0.05	0.02	-0.11	**-0.29**	-0.07	-0.26	-0.24	**-0.30**	-0.26	**-0.31**	-0.22	-0.22	-0.26	-0.11	0.00	-0.24
Microtox		1.00	0.00	0.01	0.02	0.03	-0.05	-0.13	0.12	0.14	-0.10	-0.12	0.10	-0.11	-0.25	**-0.29**	-0.18	-0.21	-0.16	-0.13	-0.15	0.04	0.21	-0.17
Larval			1.00	0.13	**-0.52**	**-0.36**	**-0.49**	**-0.28**	**-0.42**	-0.19	**-0.32**	-0.23	**-0.28**	-0.18	**-0.27**	-0.24	-0.21	-0.16	-0.25	**-0.29**	-0.22	**0.35**	-0.11	-0.23
Polychaete				1.00	-0.06	0.06	-0.23	0.13	-0.07	0.03	-0.09	0.13	0.06	0.12	0.13	0.13	0.17	0.16	0.13	0.14	0.16	0.12	0.12	0.10
Resin acids					1.00	**0.65**	**0.61**	0.30	0.39	0.15	**0.55**	0.33	0.39	0.35	0.21	0.18	0.34	0.32	0.18	0.33	0.29	-0.18	0.15	0.33
TVS						1.00	**0.55**	**0.31**	**0.28**	**0.29**	**0.42**	**0.33**	**0.30**	**0.27**	**0.31**	**0.29**	**0.30**	**0.30**	0.22	**0.32**	**0.30**	-0.14	0.13	**0.29**
Wood Content (visual)							1.00	**0.59**	**0.58**	0.41	**0.74**	**0.67**	**0.50**	**0.53**	0.40	**0.50**	**0.55**	**0.55**	0.34	**0.58**	**0.50**	-0.21	0.21	**0.72**
Percent Fines								1.00	**0.46**	**0.43**	**0.64**	**0.72**	**0.56**	**0.71**	**0.66**	**0.66**	**0.72**	**0.60**	**0.58**	**0.80**	**0.79**	**-0.27**	0.09	**0.64**
Ammonia									1.00	**0.43**	**0.48**	**0.36**	**0.51**	**0.51**	**0.33**	0.24	**0.34**	**0.34**	**0.35**	**0.45**	**0.46**	**-0.32**	0.07	**0.34**
Sulfide										1.00	**0.46**	**0.39**	**0.46**	**0.46**	**0.32**	**0.35**	**0.37**	**0.37**	**0.31**	**0.40**	**0.45**	-0.25	0.15	**0.39**
TOC											1.00	**0.56**	**0.42**	**0.51**	**0.44**	**0.51**	**0.52**	**0.47**	**0.33**	**0.58**	**0.59**	**-0.29**	0.17	**0.60**
Antimony												1.00	**0.62**	**0.68**	**0.60**	**0.65**	**0.86**	**0.77**	**0.50**	**0.77**	**0.75**	-0.12	0.26	**0.76**
Arsenic													1.00	**0.66**	**0.42**	**0.38**	**0.61**	**0.56**	**0.43**	**0.67**	**0.65**	-0.15	0.24	**0.57**
Cadmium														1.00	**0.54**	**0.55**	**0.75**	**0.74**	**0.51**	**0.78**	**0.85**	-0.19	0.13	**0.61**
Chromium															1.00	**0.81**	**0.63**	**0.51**	**0.84**	**0.66**	**0.69**	-0.19	0.07	**0.46**
Copper																1.00	**0.68**	**0.55**	**0.72**	**0.65**	**0.69**	-0.14	0.12	**0.52**
Lead																	1.00	**0.79**	**0.54**	**0.81**	**0.83**	-0.12	0.26	**0.75**
Mercury																		1.00	**0.43**	**0.69**	**0.73**	-0.10	0.18	**0.68**
Nickel																			1.00	**0.59**	**0.64**	-0.20	0.03	**0.38**
Silver																				1.00	**0.88**	-0.17	0.24	**0.74**
Zinc																					1.00	-0.16	0.18	**0.66**
Total LPAHs																						1.00	**0.39**	-0.11
Total HPAHs																							1.00	**0.34**
Dioxins / Furans																								1.00

Bold values indicate significant relationships (α=0.05); values above 0.5 indicate a strong linear relationship.

PAH data were OC-normalized.

τ values below and above the diagonal are mirror images; only one dataset is shown to make the table easier to read.

explained, given that these constituents were found to be positively correlated with toxicity in other bioassay tests, discussed below. The opposite pattern was observed with the Microtox test results, where percent fines, silver, and dioxins/furans were negatively correlated with increasing survivorship. The juvenile polychaete test results were not correlated with any of the sediment chemistry parameters. The larval development test results were correlated with the largest number of analytes, including percent fines, visible wood content, TOC, TVS, ammonia, sulfide, all metals, and dioxins/furans. Of these parameters, percent fines and TOC had the strongest correlations to larval survivorship (τ = -0.41 and -0.44, respectively). To investigate these relationships further, the statistics were re-analyzed reducing the sample population to only those samples collected from Shelton Harbor, the most highly impacted area (Table 7-2). In this case, resin acids, visible wood content, and ammonia showed the strongest correlations with larval survivorship (τ = -0.52, -0.49, and -0.42, respectively).

TOC, percent fines, resin acids, and visible wood content were the most highly correlated parameters with larval toxicity when considering both the entire study area dataset and the Shelton Harbor dataset. This suggests that these parameters play a role in larval toxicity. TOC and percent fines were also correlated with ammonia, sulfide, and all of the metals. So, it is possible that these other constituents associated with fine organic material also may contribute to larval mortality. Table 7-3 provides a graphical representation of the relationships among the combined bioassay test results at each station for all four tests, and the relative abundance of these wood waste-related parameters at each sample location. This table indicates that, on average, wood content and resin acids are both greater in those samples that failed toxicity tests (compare the relative length of colored bars in the pass-test category to the bars in the two fail-test categories).

In addition to environmental factors, the laboratory test method for larval toxicity should be considered. Standard protocol for the test requires that the sediment sample be thoroughly mixed with water in the test vessel and allowed to settle for 4 hours before the addition of larvae. If the sample contains significant amounts of organic fines, then those fines that settle after the 4-hour wait period may partially bury larvae and contribute to mortality, that is, mortality may be an artifact of the test method.

After performing the correlation analyses, hypothesis testing was performed to determine if there was a significant difference between pollutant concentrations in samples that failed toxicity tests and those that passed toxicity tests. In its simplest form, hypothesis testing addresses differences between data separated into two bins. In this case, the bins are toxicity test ‘pass’ and ‘fail’ categories. Significance is measured using a p-value with a threshold traditionally set at 0.05 (95 percent probability that there is a significant difference). If the test result has a p-value less than 0.05, then the difference between the datasets is deemed significant.

The benefit of this test is that there is a clear delineation between the chemistries of sediments that pass and fail a toxicity test; the chemistries are either significantly different or they are not. With correlation, the strength of the relationship between the dependent and independent variable is more difficult to interpret than with hypothesis testing; that is, there is no clear distinction between a strong relationship and a weak relationship.

If the data exhibit a normal distribution, then a parametric test is more appropriate for use in the analyses; if the data do not exhibit a normal distribution, then a non-parametric test is more appropriate. Using a parametric test on data that do not have a normal distribution violates a primary assumption of the test and produces spurious results. Non-parametric tests do not require any assumptions about the data's distribution and can be used equally well on normal and non-normal data (a parametric test will have slightly more power for detecting differences in the data if the data do in fact exhibit a normal distribution).

Based on the Kolmogorov-Smironov normality test applied to the data, as discussed above, the non-parametric Mann Whitney U-Test was chosen instead of the parametric t-test (some of the data were normally distributed and some were non-normally distributed – because the t-test is invalid for non-normal data and because we did not want to exclude any data from the analysis, the Mann-Whitney U-test was applied to all the data in this study). This is a widely used and powerful test and the one most appropriate for this analysis.

Before running the Mann Whitney U-Test, data from all of the toxicity tests were combined. If a sample failed any of the tests, it was labeled a "fail", if a sample passed all the tests, it was labeled a "pass". The test results, based on these two bins, are presented in Table 7.4. It should be noted that if this test were to be applied to each toxicity measure individually, the results would be different.

Of the 50 surface sediment samples tested, 25 samples passed and 25 samples failed toxicity tests (except for resin acids and TVS, for which only 24 and 16 samples were analyzed, respectively). The sediment chemistries of these two data populations were compared using an alpha level of 0.05. That is to say, if the Mann-Whitney p-value was greater than 0.05, then no significant difference between data populations was determined. If sediment chemistry was significantly different in the toxicity-pass and toxicity-fail groups, the p-values were bolded in Table 7-4. The "direction of difference" column in the table indicates whether sediment chemistry concentrations were significantly higher in the toxicity-fail group than in the toxicity-pass group of samples. For most analytes, this was noted as Fail>Pass; only total LPAHs indicated that concentrations were higher for the toxicity-pass group.

As can be seen from Table 7-4, samples that failed the toxicity tests exhibited significantly higher levels of the following:

- Percent fines
- Ammonia
- Sulfide
- TOC
- Antimony
- Chromium
- Copper
- Nickel
- Silver
- Dioxins/furans

Table 7-3. Results of wood waste constituents and visual observations of wood waste in surface sediment samples, based on toxicity testing results.

Sample ID	Observed Wood (percent)	TOC (percent)	TVS (percent)	Ammonia (mg/kg)	Sulfides (mg/kg)	Total Resin Acids (µg/kg)
Sample stations failing CSL criteria for toxicity tests						
SH-02	7.5	2.46	--	14.8	548	--
SH-03	5	3.8	--	11.2	155	--
SH-04	5	4.13	--	14.8	550	--
SH-05	5	3.2	--	6.33	391	--
SH-07	0.5	1.59	--	8.21	158	--
SH-19	7.5	4.44	17.72	17.1	916	4,200
SH-21	5	5.59	16.64	18.6	1,890 J	5,700
SH-22	50	5.77	19.68	30.5	969	7,400
SH-24	50	4.97	14.17	17.2	148	9,000
OB-05	0	2.35	--	11.6	761	1,000
OB-06	2.5	4.68	--	9.47	1,190	1,200
OB-10	0	2.62	--	8.26	955	920
OB-13	0	3.53	--	10.4	255	1,100
OB-14	0	1.71	--	4.28	204	--
OB-18	0	2.86	9.35	22.4	1,110	450
OB-19	0	2.6	9.25	6.83	823	1,500
Sample stations failing SQS criteria for toxicity tests						
SH-13	0.5	11	--	7.34	518	--
SH-14	10	3.1	--	18.7	1350	--
SH-26	0	1.92	2.62	8.77	510	270
SH-28	0	1.24	5.47	12	338	300
OB-03	0	2.79	--	11.7	1,240	--
OB-04	5	3.45	--	8.52	599	--
OB-09	0	2.69	--	10.8	1,530	--
OB-12	0	2.26	--	10.1	908	1,800
HI-02	0	0.571	--	6.75	4.18	1,400
Sample stations passing CSL and SQS criteria for toxicity tests						
SH-01	0	1.59	--	12.9	283	--
SH-09	0	2.17	--	7.91	192	--
SH-10	2.5	2.03	--	9.69	159	--
SH-11	10	2.32	--	4.96	541	--
SH-12	5	4.79	--	10.7	1070	--
SH-15	0	0.542	--	4.3	5.01	--
SH-16	0	0.511	--	2.76	1.19 U	--
SH-18	0	4.79	14.3	32.4	1,710	3,300
SH-20	5	5.15	12.81	17.8	1,810	2,100
SH-23	2.5	3.33	10.26	21.4	1,760	2,500
SH-25	0	2.6	10.77	8.45	950	530
SH-27	5	1.38	3.52	6.97	15.8	1,900
SH-29	0	0.594	1.55	6.67	1.42	2,000
SH-30	0	1.99	8.31	17.1	896	3,300
OB-01	0	0.878	--	15.1	6.83	--
OB-02	0	1.4	--	4.79	489	3,200
OB-07	0	0.995	--	9.34	2.25 U	--
OB-08	0.5	1.36	--	8.22	167	--
OB-11	0	2.32	--	10.3	685	--
OB-17	2.5	2.39	4.41	4.72	363	1,900
HI-03	0	1.45	--	6.55	203	--
HI-04	5	0.625	--	10.1	17.7	2,800
HI-05	0	0.799	--	7.82	9.65	--
HI-06	0	2.43	--	5.68	258	--
HI-07	0	0.68	--	5.83	1.3	--

Blue bar:	Relative magnitude within the set of values for each parameter, allowing for quick inter-parameter comparisons.
CSL	Cleanup screening level – combined results for all four toxicity tests
SQS	Sediment quality guidelines – combined results for all four toxicity tests
mg/kg	Milligrams per kilogram
µg/kg	Micrograms per kilogram
--	Not analyzed
U	Not detected
J	Estimated value

Table 7-4. Sediment chemistry toxicity test pass - fail comparison.

Analyte	Mann-Whitney p-level [a]	Direction of Difference	Valid N Pass	Valid N Fail
Percent fines	**0.001154**	Fail>Pass	25	25
Resin acids	0.907787	-	7	8
Wood content (visual)	0.147585	-	25	25
TVS	0.247997	-	8	8
Ammonia	**0.044608**	Fail>Pass	25	25
Sulfide	**0.006408**	Fail>Pass	25	25
TOC	**0.001005**	Fail>Pass	25	25
Antimony	**0.026811**	Fail>Pass	25	25
Arsenic	0.109266	-	25	25
Cadmium	0.122866	-	25	25
Chromium	**0.023657**	Fail>Pass	25	25
Copper	**0.017384**	Fail>Pass	25	25
Lead	0.062358	-	25	25
Mercury	0.082371	-	25	25
Nickel	**0.049676**	Fail>Pass	25	25
Silver	**0.005809**	Fail>Pass	25	25
Zinc	0.057168	-	25	25
Total LPAHs	**0.001608**	Pass>Fail	25	25
Total HPAHs	0.248206	-	25	25
Dioxins/furans	**0.006409**	Fail>Pass	25	25

[a] If the Mann-Whitney p-level is less than 0.05, there is a significant difference between chemistry of sediments that passed and failed toxicity tests.

[b] Non-detects were calculated as ½ the detection limit.

Bold = significant difference

There was no significant difference between passed and failed sediment samples for the following analytes:

- Resin Acids
- Wood content (visual)
- TVS
- Arsenic
- Cadmium
- Lead
- Mercury
- Zinc
- Total HPAHs

Taken together, the findings of the correlation and hypothesis testing analyses indicate that PAHs are not a source of toxicity in the sediments analyzed. Though the presence of some metals was generally correlated with toxicity, none of the individual metals concentrations exceeded sediment quality standards. Percent fines and TOC were the strongest predictors of toxicity and also strongly correlated with ammonia, visible wood content, TVS, resin acids, sulfide, all of the metals, and dioxins/furans. However, it is not possible to determine if the toxicity was caused by a combination of all or some of these constituents or simply from toxicity during the tests associated with the fines present. Also, it should be noted that dioxin/furan toxicity is a long-term bioaccumulative effect that cannot be observed in bioassay results.

Three interpretations that could follow from the statistical analyses include:

1. Toxicity is driven not by elevated concentrations of chemical pollutants, but by grain size and organic matter content of the substrate, or another physical characteristic of the sediment such as the presence of fine-grain wood waste
2. Toxicity is driven by a synergistic affect among various low-level contaminants (primarily associated with wood waste – resin acids, sulfides, ammonia, organic matter)
3. Toxicity is driven by the presence of an unmeasured contaminant.

Neither specific industrial waste inputs nor constituents associated with wood waste can be statistically linked to toxicity results, because controlled testing to isolate toxic parameters was not conducted.

The statistical analyses presented above do not prove a specific causal relationship, they simply show mathematical relationships. To determine which of the above conclusions is correct, more testing would be required. This may include toxicity identification and evaluation (TIE) testing to determine the cause of mortality in the test organisms (USEPA 2007). TIE testing results may aid in creating a causal link between toxicity and sediment chemistry, and may be used to determine if organism burial by fines is the primary factor controlling organism mortality in laboratory tests.

7.5 Comparison to Reconnaissance Survey Results

Ecology conducted a survey (reconnaissance study) of Shelton Harbor sediments (Ecology 2000) to evaluate conditions associated with long-term accumulations of wood waste in the harbor, and potential contamination associated with various chemical inputs along the shoreline. Discrete sediment samples were collected at 10 locations along the shoreline to address specific discharge points to the harbor and composite sediment samples were collected from nine broad areas (called strata) extending across the harbor. No bioassay testing was conducted as part of the study.

7.5.1 Wood Waste Assessment

For the reconnaissance study, the harbor was divided into nine strata from which 37 surface samples were collected and composited to evaluate the relative presence of wood waste. Strata boundaries were defined by bathymetry and similar use characteristics before sampling and three to five sample locations established within each stratum. TVS measurements were used as a surrogate to estimate the amount of wood debris present in sediments. The determination of wood waste content in each sample was based on sieving sample contents into two size fractions (smaller and larger than 1/4-inch [0.6 cm]) and analyzing both fractions separately; an average of 3.5 percent of the wood was larger than 1/4 inch and 96.5 percent was smaller.

Total relative wood content was reported by weight for each stratum, ranging from 5.1 to 18.5 percent. These numbers were doubled (per HDG 1999) to estimate wood content by volume, resulting in the following distribution indicated across the harbor:

Wood Content (by volume)	Portion of Inner Harbor Area
10-20%	34%
20-30%	54%
30-40%	12%

Source: Ecology (2000).

Area-weighted averaging of these numbers results in 21.2 percent wood by volume across Shelton Harbor. The highest wood content was found in strata along the south harbor shoreline, near current barge loading and concentrated rafting operations; the lowest wood content was found in strata across the Goldsborough creek alluvial fan and extending east toward Oakland Bay, the remaining half of the harbor fell into the mid-range of wood content.

The Oakland Bay study collected 26 surface samples and 24 core samples across Shelton Harbor (fewer cores as a result of refusal due either to high wood or rock content). Thirteen of the surface samples and 11 of the 1-2 foot core samples, designated as wood waste samples, were analyzed for TVS (Figure 7-1). Sample preparation did not include screening wood into ±1/4-inch (7.6-cm) size fractions, as performed for the reconnaissance study, but did include removing large chunks of wood before analysis by TVS (the large chunks of wood were not analyzed).

A comparison of TVS results by strata from both the reconnaissance study and the current study is provided in Table 7-5; data from both studies correlate well (Kendall's $\tau = 0.67$). TVS values for the current study generally fall within the range of, or are slightly lower than, values presented in the reconnaissance study, which indicate a fair amount of variability across most of the strata. TVS results from the Oakland Bay study generally confirm the reconnaissance study findings, with the lower results partially resulting from removal of large wood pieces before analysis.

Wood content estimates based on the DMMP methodology can be derived by doubling TVS results (USACE et al. 2008). A summary of surface sediment wood content based on reconnaissance study TVS data and Oakland Bay study TVS data and visual estimates are provided in Table 7-6. Substantial variability was seen when comparing visual estimates of wood volume between surface sediment and the 0-1 foot cores, reflecting the fact that samples were not collected at the exact same location (estimates in Table 7-6 are based on the higher wood content observed in either of the two samples from each location). Visual estimates of wood content are likely biased low, since the small-grain wood material is indistinguishable from the fine grain mineral portion.

Table 7-5. Comparison of Reconnaissance Study and Oakland Bay study TVS results by strata.

	Reconnaissance Study			Oakland Bay Study	
Reconnaissance Study Stratum	No. of Samples	Average TVS (%)	Range (%)	No. of Samples	Average TVS (%)
1	4	7.2	6.0 – 9.5	1	5.49
2	3	10.73	3.5 – 15.8	1	8.31
3	5	13.18	4.0 – 26.6	2	18.16
4	5	5.12	2.0 – 7.4	1	2.62
5	4	10.18	3.8 – 16.4	1	3.52
6	4	13.62	9.3 – 22.1	2	12.47
7	4	18.48	13.4 – 29.9	2	15.26
8	3	17.63	16.3 – 18.6	1	14.3
9	5	13.96	6.2 – 32.3	1	10.26
Harbor-wide		12.23			10.04

Table 7-6. Comparison (by strata) of Reconnaissance Study and Oakland Bay study wood content estimates.

	Reconnaissance Study Wood Content Estimate		Oakland Bay Study Wood Content Estimate	
Reconnaissance Study Stratum	TVS – All Wood (%)	TVS – >1/4 Inch Chunks Removed (%)	TVS – Large Chunks Removed (%)	Visual Observation (%)[a]
1	14	14	11	11
2	22	22	16	10
3	26	26	36	38
4	10	8	5	2
5	20	18	7	6
6	27	23	25	25
7	37	33	30	4
8	35	34	28	14
9	28	25	20	6
Harbor-wide	24	23	20	13

[a] Based on the higher of wood observed in the surface sediment and 0-1 foot core section at each location.

Geophysical results for Shelton Harbor (Figure 4-3) excluded approximately ½ of the harbor area, due either to physical obstructions or gravelly sediment associated with the creek deltas. The reconnaissance study identified high wood content (20 to 40 percent) across the southern

Figure 7-1. Comparison of Reconnaissance Study (Ecology 2000) and Oakland Bay study sample locations in Shelton Harbor.

portion of the harbor. The geophysical survey could not reliably map thickness of the wood-rich layer, due to acoustic signal dampening characteristics of the wood.

The best estimate of wood distribution with depth should be based on core log information displayed in Figure 5-2. Of the 12 cores advanced across the south harbor, wood was measured up to 12 feet (3.7 meters) thick at two locations, with neither core reaching the full extent of wood present. In some cases, no wood was found at the surface, but was found at depth. The vertical distribution of wood does not appear to be consistent across broad portions of the harbor. Three areas of significant wood accumulation were estimated in the harbor based on visual observations of cores, including former sawmill #4, the railway log dump, and the former pond saw.

7.5.2 Chemical Assessment

Reconnaissance study surface sediment samples collected at the 10 shoreline discharge locations were analyzed for conventional analytes (total solids, TOC, grain size, TVS), metals, SVOCs, TBTs, and PCBs; the nine composite samples were analyzed for conventional analytes and SVOCs.

SQS criteria were exceeded at 7 sampling locations by a total of 11 constituents of concern, including some metals and semi-volatiles (Figure 7-2). CSL criteria were exceeded at 6 sampling locations by 4 of the 11 SQS constituents of concern. TBTs, which do not have SMS criteria, also were found at two locations exceeding screening values. Of the nine composite samples collected, both SQS and CSL criteria were exceeded across four strata by three constituents of concern.

In this study, no surface samples exceeded either SQS or CSL criteria; only one sample in Shelton Harbor exceeded the LAET for fluoranthene. Figure 7-2 provides Oakland Bay study laboratory results for those analytes that exceeded SMS criteria in the reconnaissance study at nearby locations. In all cases, concentrations were significantly lower in the Oakland Bay study. It is likely that variability in study results can be attributable to relatively small impact areas defined by few samples collected, mixing of sediment that results from significant human activities, and significant addition of sediment from Goldsborough and Shelton Creeks.

General results of the two studies compare, as follows:

- Mercury was found adjacent to the southwest harbor shoreline in the reconnaissance study at 0.45 and 0.50 mg/kg, slightly exceeding the SQS criterion of 0.41 mg/kg; mercury was not evident in the Oakland Bay study.
- Copper was found adjacent to the marina and marine railway/vessel haul out in the reconnaissance study at 447 and 493 mg/kg, respectively, exceeding the SQS criterion of 390 mg/kg; copper was not evident in the Oakland Bay study.

- TBTs were found near the base of the marine railway launching rails in the reconnaissance study at 1,300 µg/kg butyltin ion, 4,100 µg/kg dibutyltin ion, and 1,500 µg/kg tributyltin ion. Three samples were collected in the Oakland Bay study near the marina and former marine railway, with TBTs found only near the marine railway (8.0 µg/kg butyltin ion, 30 µg/kg dibutyltin ion, and 13 µg/kg tributyltin ion), south of the vessel haul out at the end of the Pine Street right of way. Sampling conducted by Ecology in 2005 indicated TBT concentrations of 979 and 2,136 µg/kg along the marine railway rails. Sampling indicates TBT presence to be localized near the rails.

- PAHs were the most common SVOCs found in both studies. The reconnaissance study found the highest concentrations near the marina and near historical sawmill #3; the Oakland Bay study found the highest concentrations near the former marine railway and near historical sawmill #3. Both studies identified total HPAH concentrations as higher than total LPAH concentrations across the harbor.

- The reconnaissance study found three wood waste-related SVOCs (phenol, 4-methylphenol, 2,4-dimethylphenol, and benzoic acid) at elevated concentrations along the south and southwest harbor shoreline and benzoic acid near the marina. The current investigation did not find any of these compounds at elevated levels in surface samples; however, two samples collected from the south-central part of the harbor had retene concentrations of 16,000 and 21,000 µg/kg in 1-2 foot core sections (other resin acids not analyzed for the reconnaissance study also were found at high concentrations in surface and 1-2 foot core samples).

- PCB concentrations were identified at low concentrations in all samples analyzed in the reconnaissance study, but detected at only two locations (SH-01 and HI-06) in the Oakland Bay study.

- The reconnaissance study identified PCP at all chemical screening sites, except one; the SQS criterion (360 µg/kg) was exceeded at the railway log dump (400 µg/kg - estimated value) and near the marina (380 µg/kg). No PCP was detected in any samples collected for the current investigation.

- The reconnaissance study identified di-n-butylphthalate at concentrations ranging between 11 and 40 mg/kg OC at three sampling stations – two along the southern shoreline and one near the marina; the Oakland Bay study did not find this compound at any location, but did identify BEHP (ranging between 1.5 and 3.5 mg/kg OC) across the entire harbor and butylbenzylphthalate (1.0 mg/kg OC) at the Shelton Creek discharge point.

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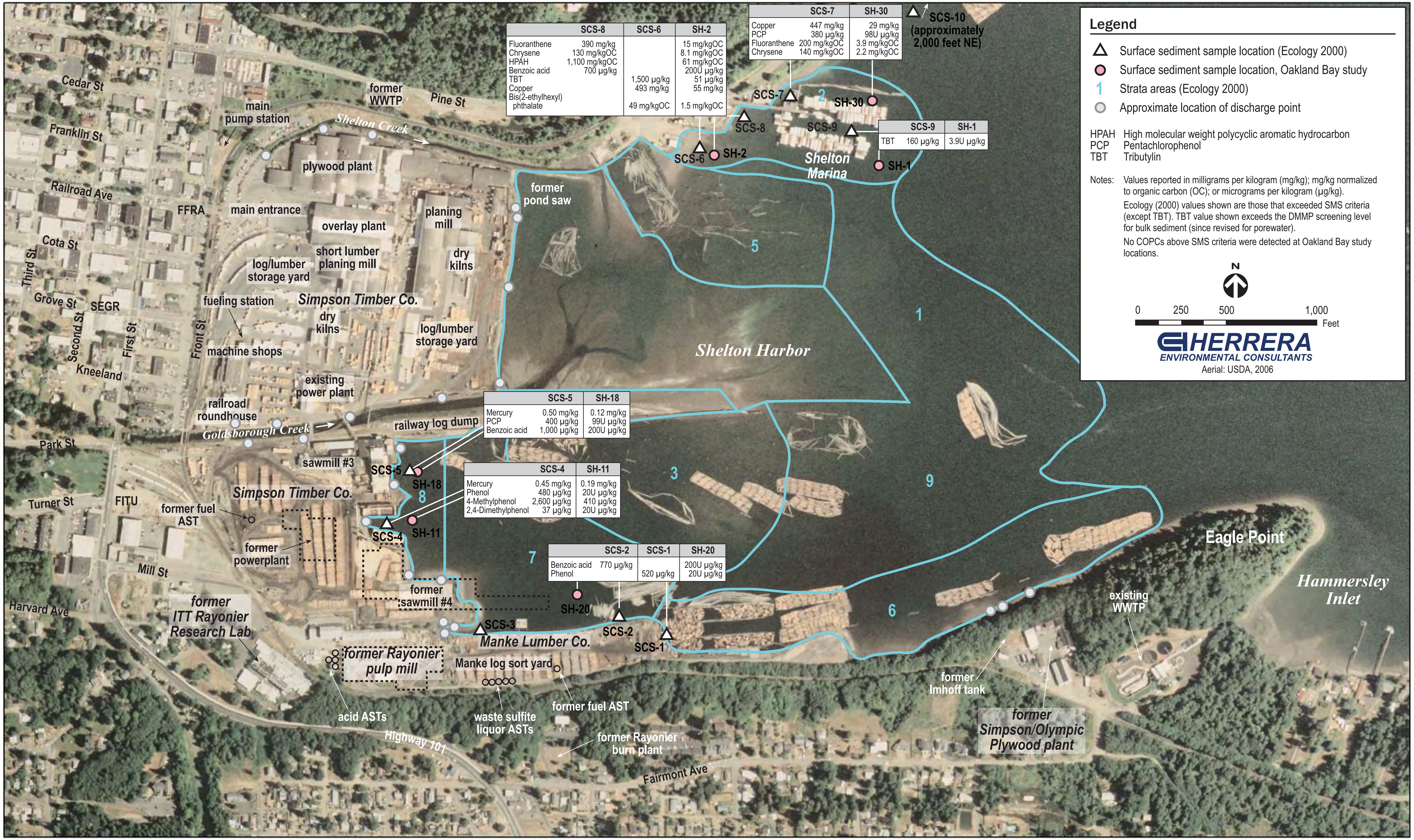

	SCS-8	SCS-6	SH-2
Fluoranthene	390 mg/kg		15 mg/kgOC
Chrysene	130 mg/kgOC		8.1 mg/kgOC
HPAH	1,100 mg/kgOC		61 mg/kgOC
Benzoic acid	700 µg/kg		200U µg/kg
TBT		1,500 µg/kg	51 µg/kg
Copper		493 mg/kg	55 mg/kg
Bis(2-ethylhexyl) phthalate		49 mg/kgOC	1.5 mg/kgOC

	SCS-7	SH-30
Copper	447 mg/kg	29 mg/kg
PCP	380 µg/kg	98U µg/kg
Fluoranthene	200 mg/kgOC	3.9 mg/kgOC
Chrysene	140 mg/kgOC	2.2 mg/kgOC

	SCS-9	SH-1
TBT	160 µg/kg	3.9U µg/kg

	SCS-5	SH-18
Mercury	0.50 mg/kg	0.12 mg/kg
PCP	400 µg/kg	99U µg/kg
Benzoic acid	1,000 µg/kg	200U µg/kg

	SCS-4	SH-11
Mercury	0.45 mg/kg	0.19 mg/kg
Phenol	480 µg/kg	20U µg/kg
4-Methylphenol	2,600 µg/kg	410 µg/kg
2,4-Dimethylphenol	37 µg/kg	20U µg/kg

	SCS-2	SCS-1	SH-20
Benzoic acid	770 µg/kg		200U µg/kg
Phenol		520 µg/kg	20U µg/kg

Legend

△	Surface sediment sample location (Ecology 2000)
●	Surface sediment sample location, Oakland Bay study
1	Strata areas (Ecology 2000)
○	Approximate location of discharge point

HPAH	High molecular weight polycyclic aromatic hydrocarbon
PCP	Pentachlorophenol
TBT	Tributylin

Notes: Values reported in milligrams per kilogram (mg/kg); mg/kg normalized to organic carbon (OC); or micrograms per kilogram (µg/kg).

Ecology (2000) values shown are those that exceeded SMS criteria (except TBT). TBT value shown exceeds the DMMP screening level for bulk sediment (since revised for porewater).

No COPCs above SMS criteria were detected at Oakland Bay study locations.

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Aerial: USDA, 2006

Figure 7-2. Comparison of Reconnaissance Study (Ecology 2000) SMS exceedances with nearby Oakland Bay study results in Shelton Harbor.

8.0 Conclusions

The Oakland Bay study was conducted to characterize marine sediment in the Oakland Bay system (Oakland Bay, Shelton Harbor, and the western portion of Hammersley Inlet) to define the bay-wide nature and extent of potential sediment contamination, including wood waste. The bay-wide approach (rather than a cleanup site-specific approach) was developed to evaluate the overall health of the bay as part of the Puget Sound Initiative process, and to identify whether there are specific source areas or areas of concern within the system.

This study emphasized locations associated with specific upland inputs to the bay and wood deposition from rafting and wood chip processing operations. The study included a geomorphic assessment to evaluate physical processes that drive the accumulation and movement of sediment across the bay, and sediment sample collection 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 for physical, chemical and biological (toxicity) analyses.

8.1 Sediment Accumulation and Transport

An evaluation of sediment transport determined that while there is some transport of fine-grained sediment (silt and clay) from Shelton Harbor to central Oakland Bay, most sediment discharged to the bay remains close to where it first enters marine waters, mostly from creeks. Coarser sediment falls close to the creek outlets, while finer grained sediment and small particles may be carried out further into the harbor and bay. The majority of sediment input to the Oakland Bay system is from Goldsborough Creek. Based on radiologic dating of three sediment cores, sedimentation in Oakland Bay ranges from 0.10 to 0.26 inches/year (0.25 to 0.66 cm/year) and in alluvial fans up to 0.39 inches/year (1 cm/year). The pattern of circulation and sediment transport in the bay is primarily determined by tidal motion – sediment transport is flood-dominated along the seabed, with the ebb tide dominated by flow at the surface containing relatively small amounts of fine-grained sediment. As a result, very little sediment moves out of the system.

8.2 Wood Debris

Wood waste enters and is distributed across the Oakland Bay system in two primary ways: low concentrations spread across deeper portions of Oakland Bay by tidal flows near the sediment bed, and significant accumulations (greater than 20 percent by volume) near both historical and current log rafting and wood processing (milling) locations. Milling primarily generates wood chips and sawdust, and log rafting primarily generates bark. Wood fibers are found in low concentrations, probably the result of historical discharge of sulfite liquor waste and fiberboard processes. Most wood mass exists in sediment as a widespread, low-concentration deposit mixed within the recently deposited marine bed surface associated with the onset of wood industry operations in the late 1800s. Geophysical survey results indicate this layer averages 3 feet (1 meter) thick (measured from 0 to 8 feet [0 to 2.5 meters]). The persistence of both significant local wood accumulation and low wood concentrations across both Shelton Harbor and Oakland Bay supports indications that wood waste, like sediment, is relatively immobile.

Four areas of significant wood accumulation were identified based on visual evaluation of sediment cores: the former saw pond, the railway log dump, and Sawmill #4 in Shelton Harbor, and at the head of the bay north of Bayshore Point. Specific boundaries of significant wood waste accumulations at these locations cannot be established with existing data. Due to poor signal resolution, geophysical techniques employed during the study could not be used to define lateral or vertical boundaries. Visual and chemical analyses would be required at many more locations to effectively evaluate accumulations on a local scale.

8.3 Chemical Analysis

Chemical analyses of surface and subsurface sediment collected from across the Oakland Bay system identified only one SMS criteria exceedance in Shelton Harbor, implicating no significant industrial inputs to the bay (fluoranthene found at 2,000 µg/kg dry weight compared to the LAET criterion of 1,700 µg/kg). Dioxins/furans, however, were found in all 63 samples collected, including both surface and subsurface sediment. Sixty-five percent of the samples exceeded 10 ng/kg TEQ, the draft maximum concentration allowable for open-water disposal under the DMMP. The highest concentrations were generally found in Shelton Harbor, but samples with low concentrations were found adjacent to samples with high concentrations, indicating significant mixing or covering of sediments in this highly trafficked area. Medium-range study area concentrations found in surface samples at the head of the bay (21.9 to 54.4 mg/kg TEQ) indicate spatially consistent input and stable sediment extending across all of Oakland Bay (reference samples collected 20 miles to the east and OSV Bold survey results had significantly lower concentrations).

No discernable source-specific spatial pattern was identified based on concentration gradients; however, dioxin/furan concentrations were much higher in Shelton Harbor, and were also higher in subsurface samples, on average (subsurface samples were collected at 25 percent of surface sample locations). This indicates that inputs to the system, at least in part, originated in Shelton Harbor and that inputs to the system appear to be diminishing, with recent, cleaner sediments likely covering older, more contaminated deposits. Considering sediment accumulation rates, it is not know why dioxin continues to be elevated in surface sediments. It is possible that there is a continuing source of dioxin, sediments from higher concentration areas are being redistributed to lower concentration areas through tidal currents, or that mixing of deeper with shallower sediments has occurred as a result of human or natural processes.

8.4 Dioxin Profiles

The following were used to generate visual profiles (bar graphs) that show the proportion of each dioxin and furan congener to total mass of congeners:

- Dioxin and furan congener source-specific information generated by USEPA
- Nearby Goose Lake sampling results available from Ecology's EIM database
- Puget Sound area-wide data from the 2008 OSV Bold survey

These visual profiles were compared to profiles from Oakland Bay study samples to identify possible dioxin and furan sources. Five of the 15 USEPA-provided congener profiles evaluated were similar to those found in Oakland Bay sediments, including:

- Technical grade PCP
- Black liquor recovery boiler stack emissions
- Forest fires
- Combustion of Bleach-Kraft mill sludge in wood residue boilers
- Unleaded fuel emissions from automobiles with catalytic converters

The liquid PCP and black liquor recovery boiler emissions appear to match the closest. Profiles were not available for sulfite waste liquor incineration; sulfite waste liquor; or boiler ash from burning salt-laden wood. Goose Lake surface and subsurface sediment congener profile patterns indicate surface sediments to be similar to those of Oakland Bay sediments (the lake received sulfite liquor waste discharges); subsurface sediment profiles were less similar. The congener profiles found across the Oakland Bay study area also are very similar to the Puget Sound sub-basins characterized by the OSV Bold survey; however, total concentrations of dioxins/furans in Oakland Bay were much higher than generally found throughout Puget Sound.

Based on available data, no specific dioxin/furan source can be definitively linked to the Oakland Bay study results without additional sampling. Nothing stands out as distinguishable from area-wide profiles, and no concentration gradient can be seen pointing to a single location/point source in the study area (although concentrations are generally much higher in Shelton Harbor than in Oakland Bay). Potential sources include pulp mill process wastewaters, discharge of discharge of sulfite liquor waste, spillage of PCP, air deposition from burning of various materials including salt-laden hog fuel and sulfite liquor (there are five historical emissions stacks along the Shelton waterfront area), and discharge of baghouse residues to the wastewater treatment plant. Similarities between Oakland Bay and Goose Lake profiles indicate a possible similar source, which could be either liquid-based, aerial emissions, or both. If aerial deposition is assumed to be the primary mechanism for distribution of dioxins/furans across Puget Sound, the high dioxin/furan concentrations found in Oakland Bay indicate the Shelton waterfront as a possible source. Additional upland testing would be required to define concentration gradients from specific emission stacks or the operational area in general.

8.5 Biological Testing

Although only one SMS chemical criterion was exceeded, 25 of the 50 bioassay samples did not meet SQS and/or CSL criteria: nine samples exceeded SQS criteria and 16 samples exceeded CSL criteria. The acute larval test had the most failures (14 CSL and seven SQS), the chronic polychaete test had seven SQS failures, and the acute amphipod and chronic Microtox test each had one SQS failure. Toxicity test pass/fail results for samples collected in areas with high accumulation of wood waste were inconsistent – samples collected from the Shelton and Goldsborough Creek discharge area generally failed the larval acute test; however, two samples collected from the Sawmill #4 wood waste accumulation area passed all tests. To evaluate a possible link between physical or chemical conditions to toxicity, both correlation analysis and hypothesis testing were performed.

When considering all data, percent fines and parameters linked to wood waste (TOC, resin acids, and TVS) were those most highly correlated to larval toxicity. When considering only Shelton Harbor data, resin acids, TVS, and ammonia showed the strongest correlations with larval toxicity. The analysis also determined that TOC and percent fines were highly correlated with ammonia, sulfide, and all of the metals. So, it is possible that these other constituents, associated with fine organic material, also may contribute to larval toxicity. Further hypothesis testing indicated that samples that failed the toxicity tests exhibited significantly higher levels of percent fines, TOC, metals (antimony, chromium, copper, lead, silver, zinc), and dioxins/furans.

Taken together, the findings of the correlation and hypothesis testing analyses indicate that percent fines and TOC are the strongest predictors of toxicity and are also strongly correlated with ammonia, wood content, TVS, resin acids, sulfide, TOC, all of the metals, and dioxins/furans. However, it is not possible to determine if toxicity was caused by a combination of all or some of these pollutants or simply from poor growth habitat associated with the fines present.

Three possible interpretations for toxicity in Oakland Bay based on the statistical evaluation are:

1. Toxicity is driven not by elevated concentrations of chemical pollutants, but by grain size and organic matter content of the substrate, or another physical characteristic of the sediment such as the presence of fine-grain wood waste.

2. Toxicity is driven by a synergistic effect among various low-level contaminants (primarily associated with wood waste – resin acids, sulfides, ammonia, organic materials).

3. Toxicity is driven by the presence of an unmeasured contaminant.

The statistical analyses presented show mathematical relationships, but cannot prove a specific causal relationship. To determine which of the conclusions above is correct, more testing would be required.

8.6 Comparisons with 1999 Reconnaissance Study

Wood content determined by TVS analysis correlated well between the 37 surface sediment samples collected for the 1999 reconnaissance survey and the 26 surface sediment samples collected from the same area for the Oakland Bay study, with the Oakland Bay study results lower in eight of the nine strata; the harbor-wide average was approximately 20 percent lower. Visual estimates of wood content made during the Oakland Bay study were approximately 30 percent lower than estimates based on TVS results for the same samples. The highest wood content area was identified across the southern harbor in both studies, and the lowest wood content area was identified across the Goldsborough and Shelton Creek alluvial fans. Core samples collected for the Oakland Bay study identified the following:

- High wood content greater than 12 feet (3.7 meters) deep at two locations in the south harbor area (neither core reached the bottom of the wood layer)
- High wood content below surface samples with little or no wood content
- Highly variable wood content at adjacent locations (possibly due to dredging or mixing from activities above)

Three areas of high wood content were identified in the harbor based on visual observations of cores: the former pond saw, the railroad log dump, and Sawmill #4. The reconnaissance study called out the area associated with Sawmill #4 and a portion of the railroad log dump based on strata averages; however, by including individual samples in neighboring strata, areas of high wood content appear similar to those identified in the Oakland Bay study (the former pond saw area was not sampled as part of the reconnaissance study).

The reconnaissance study identified 12 chemical constituents of concern in Shelton Harbor based on SMS or PSDDA criteria. Contaminants exceeded SMS criteria by factors ranging from 1.1 to 3.9 times; the PSDDA screening value for TBT was exceeded by 1.3 and 18 times at two of the locations sampled in the vicinity of the marine railway. The Oakland Bay study identified only one SMS exceedance by 1.2 times at one location; TBTs were found at one of three locations sampled, below the PSDDA screening level used by the reconnaissance study (based on a dry weight basis instead of the current pore water criterion – an approach selected to provide comparable data between the two studies). All Oakland Bay study samples collected near reconnaissance study samples indicated significantly lower concentrations of those constituents initially found to exceed SMS criteria. It is possible that:

- Over the 8 years separating the two studies, organic contaminants have degraded by physical, chemical, and biological processes
- Over the 8 years separating the two studies, chemical inputs to the harbor have decreased and the previous surface has been covered by added wood and sediment

- The distribution of chemicals is variable across the sample space, requiring additional samples to better define site conditions

8.7 Summary

This investigation has determined that sediment enters the Oakland Bay system primarily through creeks, with large-grain sediments depositing in creek deltas and fine-grain sediments redistributing across the bay; little sediment leaves the system into Hammersley Inlet. Similarly, wood waste generated primarily from wood processing along the southern portion of Shelton Harbor and log rafting across the harbor and along the Oakland Bay shoreline settles vertically, and does not move significantly through the bay system. Significant industrial chemical input was not observed across the study area and no chemical source areas were identified. The 1999 reconnaissance study did find chemical concentrations exceeding SMS criteria at eight locations along the Shelton Harbor shoreline; further sampling at historical discharge locations may be necessary to address all known potential sources.

Area-wide dioxin/furan contamination was identified as extending across the entire study area, with the highest concentrations found in Shelton Harbor. Particularly high concentrations, increasing with depth, were identified along the western shore of Shelton Harbor and into southern Oakland Bay. No concentration gradient pattern could be developed pointing to a specific source; fingerprint analysis identified PCP and black liquor recovery boiler emissions sources as the closest matches to available USEPA library profiles – PCP was reportedly used somewhere in the wood processing area west of the Shelton Harbor shoreline and sulfite liquor waste (similar to black liquor waste) was burned at various locations near the southern harbor shore.

Significant wood waste deposits were noted at four locations across the study area, and low level wood waste was found in the sediment layer that has accumulated throughout the bay since the 1800s.

Sediments in several areas failed SMS criteria for toxicity, and these areas should be considered for further investigation and cleanup. Any removal of wood waste or sediment must consider elevated dioxin/furan concentrations found across the study area.

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