WOODARD BAY SEDIMENT CHARACTERIZATION
HENDERSON INLET,
OLYMPIA, WASHINGTON

FINAL ASSESSMENT REPORT

JULY 7, 2008

Prepared for:

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Acronym List

BAZ	biologically active zone
CAS	Columbia Analytical Services
CSL	cleanup screening level
DGPS	differential Global Positioning System
DL	detection limit
DMMP	Dredged Material Management Program
DNR	Department of Natural Resources
DO	dissolved oxygen
DW	dry weight
ECD	electro conductivity detector
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
HPAH	high molecular PAH
LPAH	low molecular PAH
MLLW	mean lower low water
NAD	North American Datum
NOAA	National Oceanic and Atmospheric Administration
NRCA	Natural Resources Conservation Area
OSI	Organism-Sediment Index
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PSEP	Puget Sound Estuary Program
RPD	redox potential discontinuity
QC	quality check
SAIC	Science Applications International Corporation
SAP/QAPP	Sampling and Analysis Plan and Quality Assurance Project Plan
SIM	selective ion monitoring
SMS	Sediment Management Standards
SPI	Sediment Profile Imaging
SQS	sediment quality standards
TDL	target detection limit
TOC	total organic carbon
TVS	total volatile solids
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency

1.0 Introduction

Science Applications International Corporation (SAIC) assisted the U.S. Army Corps of Engineers, Seattle District (USACE) in an evaluation of the existing environmental conditions of the Woodard Bay Aquatic Restoration Project Area (Project Area). The Project Area includes more than 500 acres of aquatic tidelands and subtidal lands in Woodard and Chapman Bays, and the western portion of Henderson Inlet in southern Puget Sound (Figure 1). The Washington State Department of Natural Resources (DNR) is the land owner of the property.

USACE conducted this study in partnership with DNR under Section 22 of the Water Resources Development Act, Planning Assistance to the States Program. The Project Area is the location of the former South Bay Log Dump that was operated by Weyerhaeuser from 1928 to 1985. The focus of the study was to complete a preliminary characterization of wood debris accumulation from the log dump activities and evaluate whether existing submerged wood debris and possible contamination from in-water log dump structures are impacting sediment quality at the site.

1.1 Site Description

The Project Area is located in Henderson Inlet (Thurston County, WA), which includes the Woodard Bay Natural Resources Conservation Area (NRCA). The NRCA was designated by the legislature for its unique wildlife and habitat features including the largest maternity bat roost in Washington State, an important haul-out area for harbor seals, and nesting and breeding areas for waterfowl. The Project Area and vicinity consists of the largest intact, undeveloped, protected shoreline areas in southern Puget Sound.

Water depths within Henderson Inlet range from intertidal to -60 feet mean lower low water (MLLW), with an average depth of -25 feet MLLW. The inlet is generally described as a low energy, depositional environment, although several points exposed to longer northern fetches exhibit more active sediment transport. Woodard and Chapman Bays receive freshwater discharge from Woodard and Sleepy Creeks, respectively. Exposed mudflats are present in the bays during extreme low tides. Sand and gravelly tideflats are present around Weyer Point, which separate Woodard and Chapman Bays. The nearshore and estuarine environments also include substantial salt marsh areas. Upland areas are relatively undeveloped and are composed of plant species characteristic of Puget Sound second-growth lowland forests, including Douglas fir, big leaf maple, and western cedar (Hart Crowser 2007a).

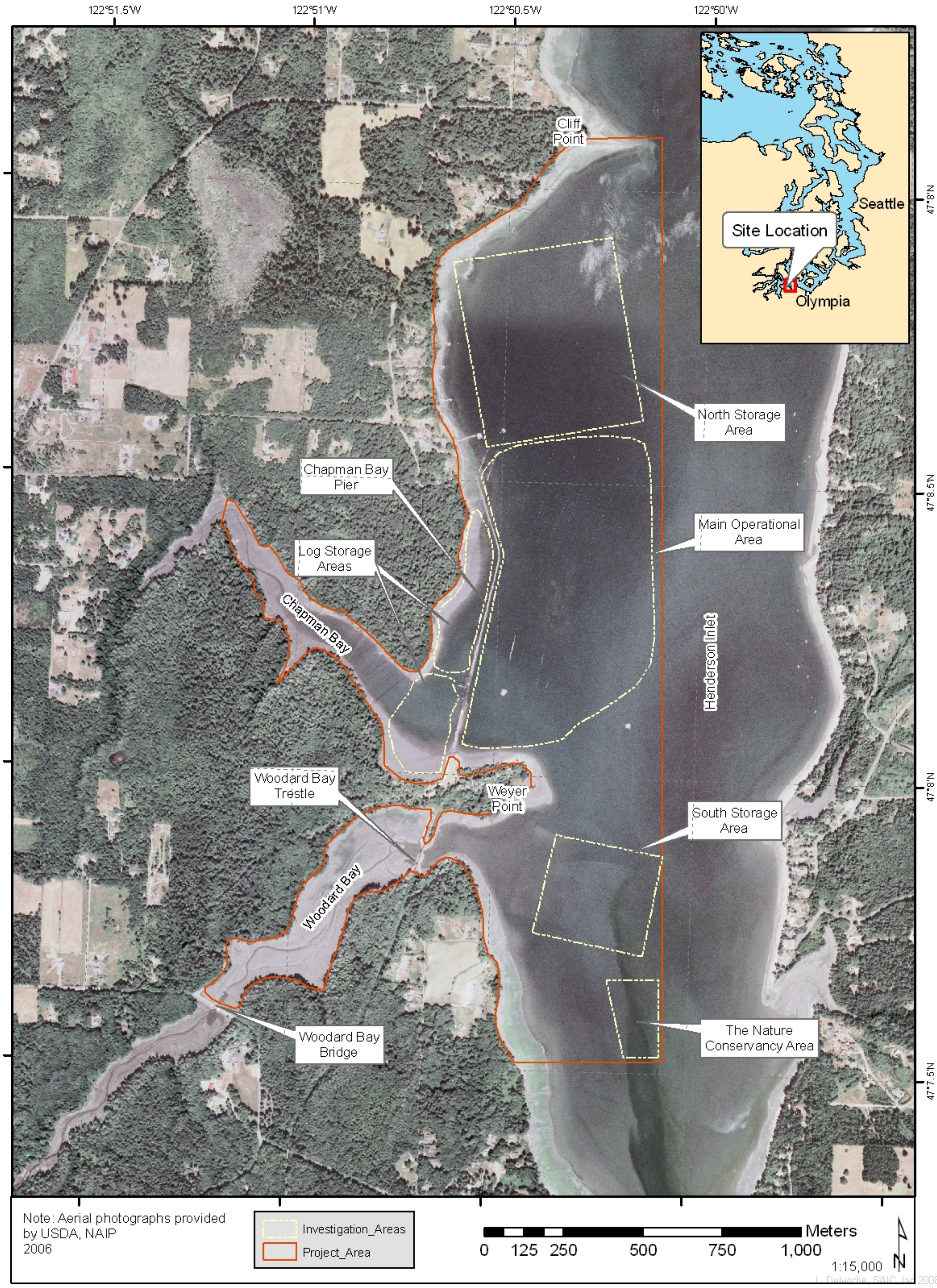

Figure 1. Woodard Bay Aquatic Restoration Project Area

(Source data for map from Hart Crowser 2007a)

1.2 Site History

The site was operated as the Weyerhaeuser South Bay Log Dump, whose activities included extensive log rafting for storage prior to transport to lumber mills. Operations occurred from 1928 to 1985. Railcars were positioned on the trestle and logs were dumped directly into the water. The logs were placed in rafts and stored in the north and south storage areas until they were towed to the Weyerhaeuser mill in Everett, WA. Sediment dredging occurred along the west side of the Chapman Bay Pier approximately every 2 years from 1930 to 1980 to maintain water depths. Dredged material was placed in open water or along a railroad sidetrack located approximately one half mile south of the main facility (Anchor 2005). In 1988, DNR purchased the uplands, tidelands, and all improvement south of the former South Bay Log Dump. Prior to the ownership transfer, Weyerhaeuser removed the Bunker "C" oil tank and a bridge over the railroad. Additional structures removed included a three-car garage, bunkhouse, and 8,000-gallon wooden water tank (Hart Crowser 2007a).

In 1989, Hart Crowser was contracted by Weyerhaeuser to perform an environmental assessment to complete the sale of the property. The assessment, which was mostly based on upland conditions, concluded that there was "limited potential for contamination in the sediment, soil, and groundwater of the site." The limited investigation identified the primary sources of contamination as petroleum products from spills associated with upland fuel oil tanks and onsite dredge spoils dumping (Hart Crowser 1989). However, the quality of the data collected for the assessment does not meet current methodology requirements (Ecology 2003), and no information was gathered regarding the presence of wood debris in aquatic sediments.

1.3 Previous Investigations

This section provides summaries of previous investigations conducted in the Project Area, including recent surveys and investigations conducted by Hart Crowser under contract to DNR. These studies provided important preliminary information on site characteristics, identified data gaps, and identified suitable sampling methods that helped to guide the study design for this project.

1.3.1 Environmental Site Assessment for Conservation Lease Area

An environmental site assessment was conducted by the Natural Conservancy of Washington (the Conservancy) to obtain a conservation lease on submerged aquatic lands in the southern portion of the Project Area (see Figure 1) (Anchor 2005). The site is 10.2 acres and supports Olympia oyster restoration efforts by the Conservancy. A bathymetry survey at the site identified a gently sloping bottom with water depths ranging from –5 to –2 feet MLLW. Wood materials associated with past Weyerhaeuser activities were the only potentially deleterious substance, as defined by the Sediment Management Standards (SMS), which could be present at the site.

A site reconnaissance included side scan sonar and Sediment Profile Imaging (SPI). The side scan sonar survey at the 120-acre site showed no detectable logs or other large objects on the sediment surface. SPI data were collected at approximately 25 locations, which included 12 stations in the Conservancy area and 13 stations in the South Storage Area (Figure 2). The most northern SPI location in the South Storage Area (Station S01) identified approximately 20 percent wood debris coverage. This location is at the northern end of a row of pilings comprising the historical log storage anchor pilings. All other locations identified less than one percent wood debris coverage. The environmental site assessment concluded that based on restoration potential, the minimal distribution of woody material at the Conservancy area did not appear to warrant clean up or regulatory action.

1.3.2 Historical Characterization Report Woodard Bay Aquatic Restoration Project

A historical characterization report was prepared by DNR in support of the Woodard Bay Aquatic Restoration Project (Hart Crowser 2007a). The report reviewed the historical records to determine likely locations of wood debris accumulation and disturbed habitat, evaluate the extent of pilings and over-water structures, and identify target areas for field investigations. The report also incorporated additional information provided by recent diver surveys conducted by the U.S. Environmental Protection Agency (USEPA).

The report concluded that the area around Chapman Bay Pier did not exhibit significant accumulations of logs or other large woody debris. This area was initially identified as a primary area of likely wood debris accumulation. When visible during the USEPA diver survey, the wood debris consisted of bark and small pieces of wood, with isolated occurrences of sunken logs. Surficial accumulation of bark and other small debris and isolated incidences of sunken logs were observed in the North Storage Area. Isolated occurrences of sunken logs in intertidal areas were noted at the mouths of Woodard and Chapman Bays. Further investigations were recommended as follows:

- The North Storage Area was recommended for further investigation to confirm the areal extend of surficial wood debris and estimate volume of debris within the biologically active zone (BAZ; defined as 0 to 1 feet). To the extent possible, the depth of wood debris should be established. Sediment quality in areas adjacent to existing piles should be evaluated.
- Similar evaluations were recommended in the Main Operational Area, with a greater number of surface and subsurface sediment samples to characterize impacts associated with creosote pilings.
- The South Storage Area appeared to have minimal data gaps based on the Conservancy study (Anchor 2005).
- Only a few logs were noted at the mouth of Woodard Bay and visual confirmation was recommended as part of the habitat survey (Hart Crowser 2007b).

Recommended investigations at the entrance to Chapman Bay included evaluation of surficial and subsurface extent and volume of wood debris, sediment chemistry, and characterization of the biological community.

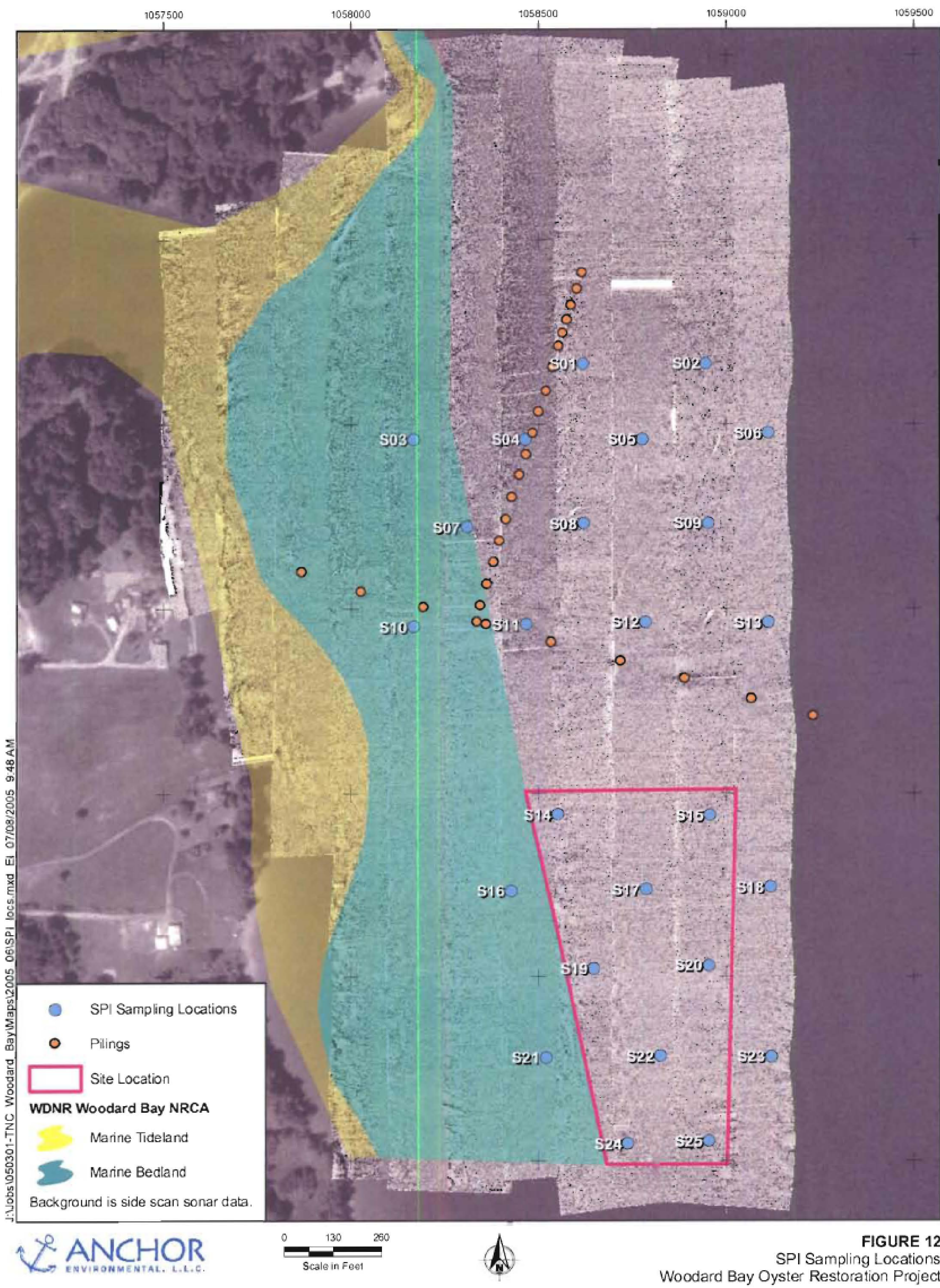

Figure 2. 2005 SPI Locations in the Conservancy and South Storage Areas (Anchor 2005)

1.3.3 Woodard Bay Intertidal Habitat Survey

A reconnaissance of intertidal habitat associated with the Project Area was conducted in support of the Woodard Bay Restoration Project (Hart Crowser 2007b). The objectives of the survey were to describe the types and locations of intertidal habitat, identify characteristics or dominant species within each habitat, and provide a qualitative assessment of the general health of the benthic communities associated with those habitats.

The Project Area included upland, riparian, freshwater wetland, tidal stream, and estuarine mudflat and sand flat habitats. Artificial habitats, in the form of historical in-water structures, were also present. Overall, the intertidal benthic communities appeared healthy, with many different species and numbers of organisms. The benthic habitats appeared physically stable and were often in depositional environments. Many long-lived epifaunal and infaunal species (littleneck, horse, and butter clams; crabs) were present and abundant. Sediments were typically well oxygenated, providing a significant potential BAZ. Macro-algae and natural large woody debris were present throughout the site and provided habitat for small epibenthic organisms (e.g., amphipods, snails) and refuge and foraging habitat for aquatic organisms such as juvenile fish.

The presence of pilings throughout the site has contributed to the productivity of hard shell clams in the Project Areas, by altering the sediment structure to favor these species. The accumulation of barnacle and mussel shells around the piles transforms the substrate from mud to a mixed fine substrate favored by bivalves.

1.3.4 Woodard Bay Pile and Structure Survey

A piling survey of the Chapman Bay Pier and Woodard Bay trestle was conducted in support of the Woodard Bay Aquatic Restoration Project (Hart Crowser 2007c). The focus of the survey was to document the integrity of the structures, determine the approximate number and condition of pilings, document existing biological communities associated with the piles, and assess the health of adjacent intertidal/subtidal communities.

The Chapman Bay Pier was reported to be in fair condition, but many structural supports, decking, and pilings showed wood rot and deterioration. Part of the pier was damaged in a fire and was determined to be unfit for load-bearing activities. Minor amounts of creosote were observed to be locally dripping from the pier, but it was not a widespread condition. The Woodard Bay trestle was determined to be in good condition. Similar to the Chapman Bay Pier, the pilings were dipped in creosote and localized dripping from the structure was observed.

It was noted in the report that a locally well-known colony of bats roosts in the central portion of the Chapman Bay Pier, starting just north of the burned area and the northern side spur. There is some metal flashing associated with the pier decking through this region, which could be the reason for the bat's exclusive use of this area.

1.3.5 Woodard Bay Underwater Video and Sub-Bottom Profiling Surveys

Towed underwater video and sub-bottom profiling surveys were conducted at the Project Area as a preliminary investigation of wood waste distribution and to characterize the general health of existing subtidal biological assemblages (Hart Crowser 2007d). The sub-bottom survey was primarily designed to test the efficacy of this technology for identifying areas of wood waste accumulation. The underwater video survey results were comparable to the previous USEPA diver surveys but with better location resolution and greater areal coverage. Appreciable wood waste was observed in four areas:

- The northeast portion of the North Storage Area;
- Along a north-south orientation in the Main Storage Area, approximately 200 feet east of the Chapman Bay Pier;
- Immediately inshore of the Chapman Bay Pier; and
- In a portion of the former South Storage Area.

Wood waste consisted of bark and small pieces of wood, and was typically present at 10 or 20 percent coverage, but as high as 90 percent (Figure 3). The benthic community appeared to be relatively healthy and did not appear to be significantly altered by wood debris.

The sub-bottom profiling trial survey did not provide obvious, conclusive indications of the presence or absence of wood debris at the Project Area. However, an anomalous response in one area (Transect 7) near the former North Storage Area coincided with the presence of surface wood debris identified by the USEPA diver survey and the towed video survey. Further characterization of the North Storage Area, particularly along Transect 7, was recommended.

1.3.6 Summary of Data Gaps

The previous investigations conducted in the Project Area provided important preliminary site characteristics, and identified the following data gaps to be addressed by this study:

- *North Storage Area:* The horizontal and vertical distribution of wood debris needs to be determined, particularly near the northern boundary. Sediment quality in areas adjacent to existing piles needs to be evaluated.
- *Main Operational Area*: The horizontal and vertical distribution of wood debris needs to be determined. Impacts to sediment quality need to be determined from the presence of creosote pilings.
- *Chapman Bay Pier Area*: The horizontal and vertical distribution of wood debris east of Chapman Bay Pier needs to be determined. Impacts to sediment quality need to be determined from the presence of creosote pilings.
- *South Storage Area*: Impacts to sediment quality need to be determined from the presence of wood debris (20 percent coverage) in the northern portion of this area.

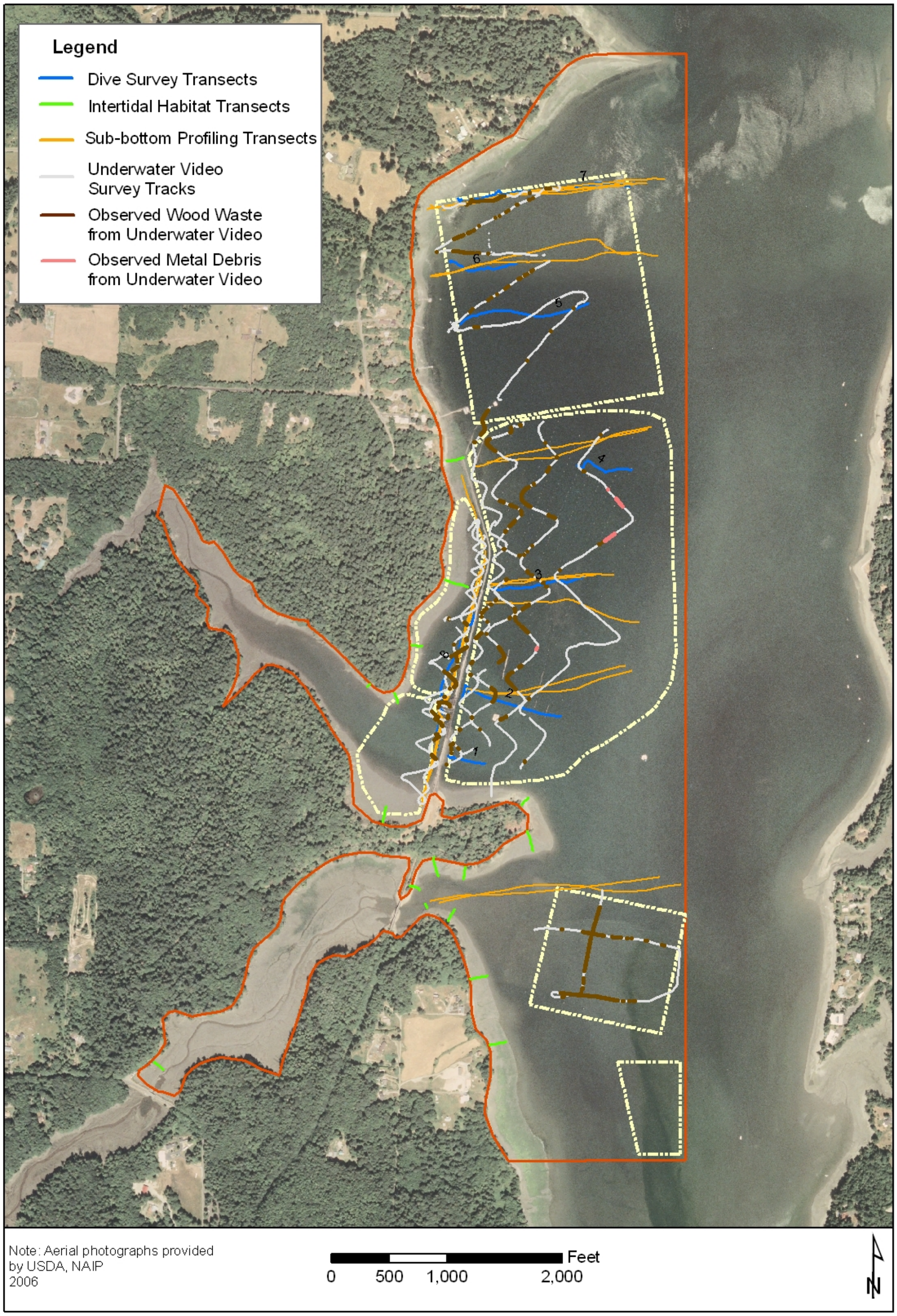

Figure 3. Compilation of 2007 Survey Results (Hart Crowser 2007d)

2.0 Project Scope and Objectives

The overall project objective for this investigation was to complete a preliminary characterization of wood debris accumulation in the Project Area and determine whether remediation or restoration may be required based on observed impacts at the site. The specific study objectives are listed below. The types of data collected to address the study objectives, including the purpose, evaluation criteria, and data decisions, are summarized in Table 1.

- Determine the location and extent, including estimates of volume, of wood waste accumulation in surface sediments in investigation areas using SPI and plan-view photography and surface sediment grab samples.
- Determine the vertical extent of wood waste accumulation in investigation areas using subsurface core sampling and video probing.
- Determine the horizontal and vertical extent of chemical contaminants in investigation areas associated with creosote-treated pilings using surface sediment grabs and subsurface cores.
- Evaluate benthic habitat conditions in investigation areas using SPI and plan-view photography and assess whether impacts are occurring due to wood waste accumulation or the presence of chemical contaminants.
- Identify locations, if any, where the confirmed presence of wood waste appears to be a hazard based on impacts measured using SPI and plan-view photography, video probing, and sediment chemical analyses (e.g., presence of hazardous substances associated with woody debris such as ammonia, sulfides, phenols, benzoic acid, and benzyl alcohol [Kendall and Michelsen 1997]).
- Collect data at the Project Area that would support a feasibility study, if a remediation or restoration project is defined in the future.

Table 1. Data Types for Addressing Study Objectives

Data Type	Purpose	Evaluation Criteria	Data Decisions
SPI	Photography of the surface sediment profile (up to the top 20 cm)	OSI (greater than +6) Infaunal Successional Stage (presence of Stage III)[1]	Estimate percent wood waste by volume and measure impacts on benthic habitat conditions
Plan-View Photography	Plan-view photography of the sediment surface (approximately 20 by 30 cm area)	--	Identify presence and extent of wood waste in conjunction with SPI; identify physical and biological surface features
Subsurface Video Probing	Subsurface video photography to evaluate presence and absence of wood debris	--	Identify vertical extent of wood waste (presence and absence) with confirmation through subsurface cores
Surface Sediment Grabs	Collect surface sediments within the BAZ (0 – 30 cm) for SMS chemical analysis and estimate percent wood waste	SQS and CSL chemical criteria under SMS	Confirm SPI estimates of wood waste by volume and determine whether chemical contaminants (e.g., from creosote pilings) exceed SMS criteria
Subsurface Sediment Cores	Collect surface and subsurface sediments for SMS chemical analysis and estimate percent wood waste	SQS and CSL chemical criteria under SMS	Confirm video probe estimates of subsurface wood waste accumulation and determine whether chemical contaminants (e.g., from creosote pilings) exceed SMS criteria

Notes:

1. The evaluation criteria for SPI parameters are described in Section 5.1.

CSL = cleanup screening levels

OSI = organism-sediment index

SQS = sediment quality standards

3.0 Study Background

This study was conducted by USACE in partnership with DNR under Section 22 of the Water Resources Development Act, Planning Assistance to the States Program. The study was designed and implemented in consultation with the Washington State Department of Ecology (Ecology). Sediment sampling, laboratory analysis, and data evaluation procedures followed Ecology's Sediment Sampling and Analysis Plan Appendix (Ecology 2003) for meeting the requirements of the Washington State SMS (Chapter 173-204 WAC).

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4.0 Field Sampling Summary

This section provides a brief summary of the field sampling program for the Woodard Bay sediment characterization study, including study design and field sampling methods. All sampling activities were conducted aboard the research vessel *Peter R*, owned and operated by Marine Sampling Systems of Burley, Washington. Detailed descriptions of field and analytical procedures and sampling operations are provided in the Combined Sampling and Analysis Plan and Quality Assurance Project Plan (SAP/QAPP) (SAIC 2008a) and Cruise Report (SAIC 2008b).

4.1 Study Design

The study design was developed to expand upon the previous investigations conducted in the Project Area and to address the objectives outlined in Section 2.0. Four investigation areas were surveyed: the North Storage, Main Operation, South Storage, and the Chapman Bay Log Storage Areas (Figure 1). Sampling locations for each data type collected (Figures 4 and 5) included specific locations occupied during previous investigations (primary sampling locations), and randomly placed locations using grid cells within each investigation area. One location was placed near the Woodard Bay trestle to evaluate the impacts of creosote-treated piles to underlying sediments. Because the trestle limits access to Woodard Bay (including log storage), the previous investigations in the Project Area did not identify Woodard Bay as an area requiring the characterization of woody debris (Hart Crowser 2007a). The data collection methods are summarized in Sections 4.2 to 4.7.

The initial component of the investigation was to conduct an area-wide survey using SPI and plan-view cameras to evaluate the extent of woody debris in surface sediments, and assess the relative benthic habitat quality. SPI photography provides a cross-sectional photograph of the sediment/water interface (in profile) and near-surface sediment. The plan-view camera provides a photograph of the sediment surface.

The vertical extent of wood debris was evaluated through the use of a subsurface sediment video probe. This device is constructed to allow real-time observations of the sediment as the video probe is advanced into the sediment column. The physical characteristics of the sediment can be determined with depth, including the presence or absence of wood debris.

A major component of the study was utilizing the SMS interpretive criteria for sediment chemistry to characterize the nature and extent of potential contamination in the investigation areas. Sampling locations were placed in areas of interest based on previous investigations (i.e., wood waste accumulation and potential impacts from creosote pilings) and provide spatial coverage throughout the investigation areas.

Fourteen surface sediment samples were analyzed for SMS chemicals and conventional sediment parameters, including ammonia, total sulfides, total organic carbon, total volatile solids, total solids, and grain size. The chemical results were compared to the SMS Sediment Quality Standards (SQS) and Cleanup Screening Level (CSL) numeric criteria. The SMS provides a regulatory basis, management goal, and decision process for the characterization and cleanup of contaminated sediments (WAC 173-204). The SQS are used as a sediment quality goal for Puget Sound sediments and provide criteria for chemicals of concern below which no effects are expected. CSLs are used as an upper regulatory level for source control and cleanup decision making where minor adverse effects are expected. The SMS chemical criteria, in conjunction with other survey data, are used to assess whether anthropogenic contaminants in sediments are a potential source of adverse effects on biological resources. The chemical analyte list, analytical methods, target detection limits, and comparative criteria can be found in the SAP/QAPP (SAIC 2008b) and are discussed in Section 4.7.

The vertical extent of wood debris and potential chemical contamination was evaluated by the collection of subsurface sediment cores at 10 locations (Figure 5). The subsurface sediment collection and evaluation included a physical description of the stratigraphy, including presence or absence of wood waste, as well as the collection of sediment interval composites for chemical analysis and archiving. Subsurface sediment sampling locations were located so that the vertical extent of contamination could be determined in the event that adverse impacts were observed in overlying surface sediments. The subsurface sediment intervals to be analyzed were selected in the field based on the physical character of the core samples, including visual observations indicating potential contamination and/or presence of wood debris. The remaining samples were archived for potential future analysis. However, the potential analysis of archived subsurface sediment samples and toxicity testing of surface sediment samples were not within the budgetary scope of this project.

4.2 Navigation and Positioning

The positioning and recording of actual sampling locations was accomplished using a Trimble differential Global Positioning System (DGPS). The DGPS uses U.S. Coast Guard differential beacons to increase the positional accuracy of the satellite positioning system to ±2 meters. All geographic coordinates were recorded as latitude and longitude to the decimal minute and referenced the North American Datum (NAD 83). Water depth was determined using a fathometer or a lead-line (weighted measuring tape) to measure to the nearest 0.1 foot from the water surface to the mudline. The target sample coordinates are provided in Table 2 and sampling locations are displayed in Figures 4 and 5.

Table 2. Sampling Locations and Data Collected

Station	Latitude (dec. deg.)	Longitude (dec. deg.)	SPI Photographs	Plan-View Photographs	Video Probe	Subsurface Cores	Surface Grabs
WB-01	47.148220	122.838993	X	X	X		
WB-02	47.148225	122.840120	X	X	X		A
WB-03	47.129915	122.838252	X	X	X		X
WB-04	47.148013	122.841503	X	X	X	X	
WB-05	47.147962	122.842165	X	X	X		
WB-06	47.147853	122.842757	X	X	X		X
WB-07	47.147312	122.840335	X	X	X		
WB-08	47.145943	122.842297	X	X	X	X	
WB-09	47.145928	122.839898	X	X	X		X
WB-10	47.145702	122.837890	X	X	X		
WB-11	47.144018	122.841022	X	X	X		
WB-12	47.143517	122.838997	X	X	X		X
WB-13	47.142803	122.842093	X	X	X	X	
WB-15	47.142370	122.839317	X	X	X		
WB-16	47.142378	122.836567	X	X	X		X
WB-17	47.141207	122.842400	X	X	X		X

Station	Latitude (dec. deg.)	Longitude (dec. deg.)	SPI Photographs	Plan-View Photographs	Video Probe	Subsurface Cores	Surface Grabs
WB-18	47.140987	122.840482	X	X	X	X	
WB-19	47.140735	122.838407	X	X	X		A
WB-20	47.139767	122.841283	X	X	X	X	
WB-20A	47.139613	122.841660			X		
WB-21	47.139260	122.839295	X	X	X		X
WB-22	47.139023	122.842797	X	X	X		X
WB-23	47.139142	122.836382	X	X	X		
WB-24	47.129265	122.835665	X	X	X		
WB-25	47.138727	122.837835	X	X	X		
WB-26	47.137910	122.843120	X	X	X		X
WB-27	47.137355	122.843052	X	X	X		
WB-28	47.137377	122.840313	X	X	X	X	
WB-29	47.137222	122.837425	X	X	X		A
WB-30	47.137043	122.842010	X	X	X		X
WB-31	47.136467	122.842797	X	X	X	X	
WB-32	47.136463	122.840865	X	X	X		
WB-33	47.135858	122.840012	X	X			
WB-34	47.135742	122.844813	X	X	X		
WB-35	47.135330	122.843325	X	X	X		X
WB-36	47.135567	122.838205	X	X	X		X
WB-37	47.134710	122.844855	X	X	X		X
WB-38	47.134807	122.842700	X	X	X	X	
WB-39	47.134171	122.843997	X	X			
WB-40	47.134263	122.841800	X	X	X		A
WB-41	47.133555	122.844965	X	X	X		A
WB-42	47.131060	122.844190	X	X	X		X
WB-42B	47.130823	122.844268			X		
WB-43	47.131322	122.841677	X	X	X	X	
WB-44	47.131028	122.838247	X	X	X	X	
WB-45	47.131043	122.836630	X	X	X		
WB-46	47.134372	122.837433	X		X		
WB-47	47.133397	122.839058	X		X		
WB-48	47.132648	122.837400	X		X		
WB-50	47.148152	122.840835			X		
Totals			47	44	48	10	19

Notes:

X = Sample collected

A = Sample archived

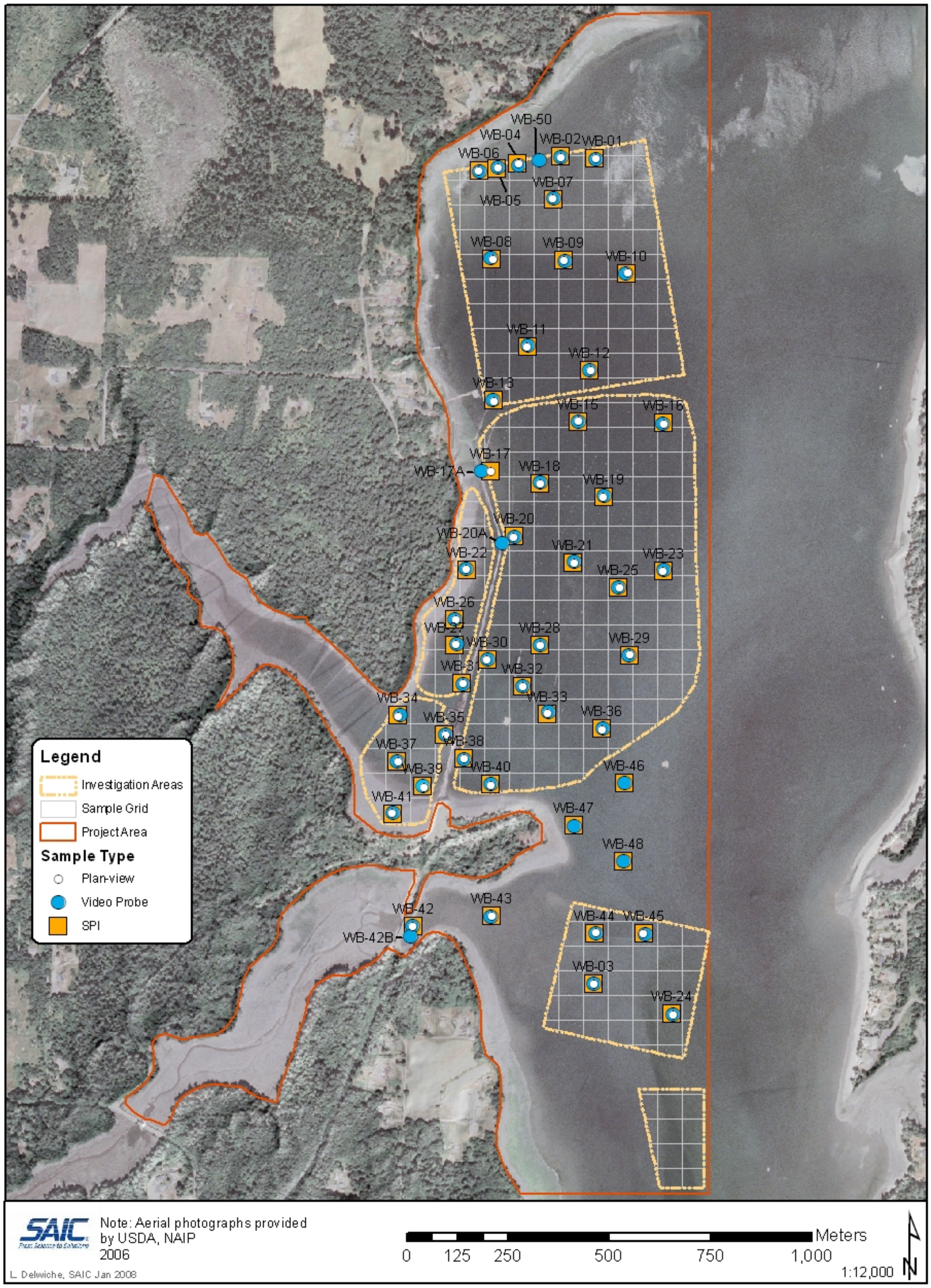

Figure 4. SPI, Plan-View, and Video Probe Sampling Locations

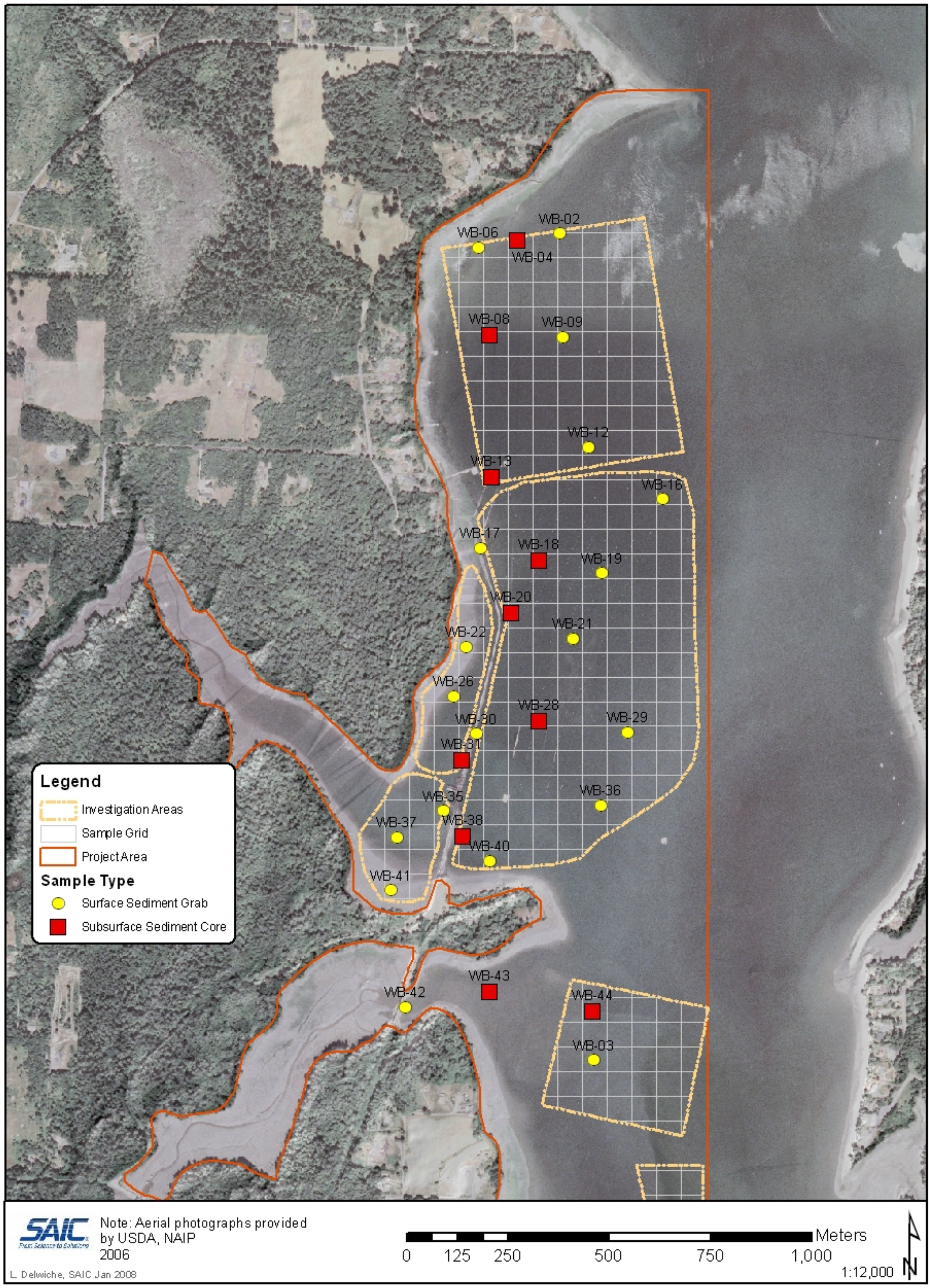

Figure 5. Surface Grab and Subsurface Core Sampling Locations

4.3 SPI and Plan-View Photography

SPI photography was conducted using a Benthos model 3731 sediment profile camera system equipped with an MTS digital camera. SPI photography provides a cross-sectional "profile" photograph of surface sediments (an area 20 cm high by 14 cm wide) (Figure 6). Triplicate SPI photographs were collected at 47 locations for a total of 141 images for analysis (Figure 4). The SPI survey was used to assess the condition of the benthic habitat and the physical characteristics of the surface sediment. Parameters assessed using the images include:

- Visual estimate of percent wood debris by volume,
- Grain size mode and range,
- Depth of apparent redox potential discontinuity (RPD),
- Infaunal successional stage, and
- Calculation of the Organism-Sediment Index (OSI).

These physical and biological parameters were measured from the SPI images using a computer image analysis system (Appendix A). A description for each of these parameters is provided in Section 5.1.

Plan-view underwater still photography was conducted using a downward looking PhotoSea underwater camera and strobe that was mounted to the SPI camera. The plan-view camera photographs a 20 by 30 cm area near the front of the SPI camera faceplate that provides a high resolution image of the sediment surface. Two plan-view photographs were collected at 44 locations, for a total of 88 images for evaluation. The surface sediment images were evaluated in conjunction with the co-located SPI images to provide a visual estimate of percent wood debris at each location.

4.4 Subsurface Sediment Video Probe Survey

Subsurface sediment video was collected using a Marine Sampling Systems video probe prototype, adapted for deployment using an existing vibracore assembly (Figure 7). The video probe consists of an RGB video camera illuminated with four LED lights mounted inside a 6-foot assembly with a conical Lexan lens (36 mm diameter field of view). The video probe was deployed at 48 locations and advanced to a depth of 6 feet below mudline or until reaching refusal (Figure 2). If needed, the vibracore assembly was used to advance the probe into the sediment. Video footage and audio descriptions were recorded to VHS tapes and later transferred to DVD. Evaluation of the video probe data (determination of percent wood debris over 0.5-foot depth intervals) was conducted by Browning Environmental Services, Olympia, Washington (Appendix B).

4.5 Surface Sediment Grabs

Surface sediment grabs were collected at 19 locations using a 0.25 m^2 hydraulic power van Veen grab sampler (Figure 5). Surface sediment samples were collected from the biologically active zone of 0 to 1 foot, as determined by project proponents. Samples from 14 of the 19 locations were submitted for chemical analysis; samples from the remaining five locations were archived for potential future analysis. Visual descriptions of the sediment grabs can be found in the Cruise Report (SAIC 2008b). Samples were hand-delivered by SAIC personnel to Columbia Analytical Services' (CAS) laboratory in Kelso, Washington on February 27, 2008.

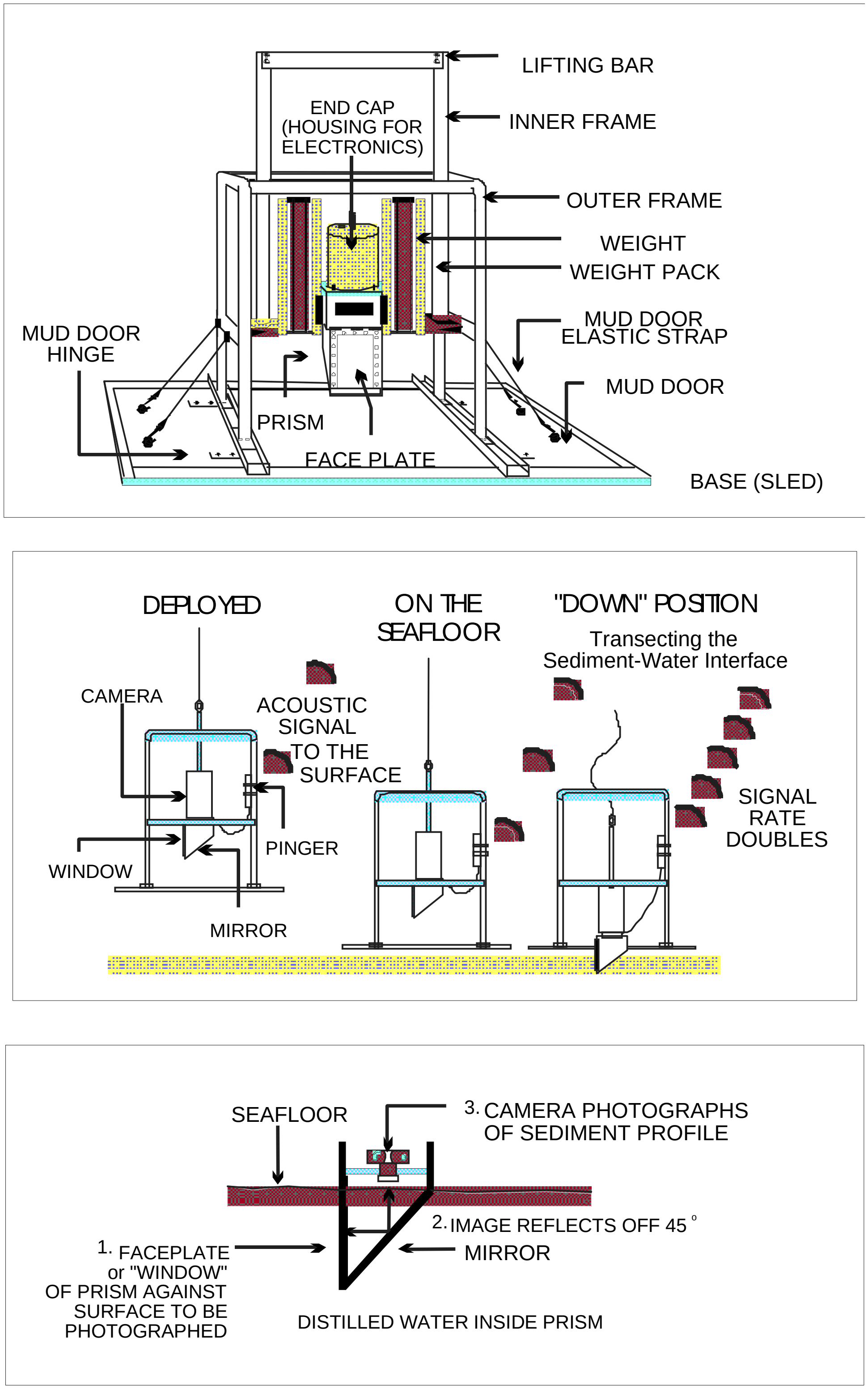

Figure 6. Schematic Diagram of Sediment-Profile Camera and Sequence of Operation on Deployment

Marine Sampling Systems Vibracore Assembly Deployed from the R/V *Peter R*

6-Foot Video Probe Prototype with Conical Lexan Lense

Figure 7. Marine Sampling Systems Video Probe Prototype System

4.6 Subsurface Sediment Cores

Subsurface sediment cores were collected at ten locations using a hydraulic vibracore sampler fitted with 7-foot aluminum core tubes (Figure 5). The cores were transported to SAIC's processing facility in Bothell, Washington on February 25, 2008, and were processed on February 26–27, 2008. The surface interval (0 to 1 foot) of all cores, and the 1- to 3-foot intervals of 8 of the 10 cores (a total of 18 samples) were submitted for chemical analysis. All remaining core intervals were archived for potential future analysis. Subsurface sediment core logs are provided in the Cruise Report (SAIC 2008b). To ensure compliance with holding time requirements, samples were hand-delivered by SAIC personnel to CAS in Kelso, Washington on February 27, 2008.

4.7 Chemical Laboratory Analyses

All of the chemical analytical procedures used in this program were performed in accordance with Puget Sound Estuary Program (PSEP) guidelines (PSEP 1997a,b,c,d), SMS Protocols (Ecology 2003), and modifications proposed during the Sediment Management Annual Review Meetings except where noted below. Chemical analyses were conducted by CAS. The specific analyses and conventional parameters measured, analytical methods, target detection limits (TDLs), and SMS numeric criteria (SQS and CSL) are presented in Table 3. Due to matrix interference problems for some samples, the analytical laboratory could not meet the TDLs for some compounds, particularly hexachlorobenzene and both methylated and chlorinated phenol compounds. This resulted in sample detection limits (DLs) exceeding the SMS criteria in some instances. To compensate for the elevated DLs, the analytical laboratory conducted additional analyses using detector systems that were more sensitive to the specific classes of target compounds. Hexachlorobenzene was analyzed by USEPA method 8081, chlorinated phenols were analyzed using USEPA method 8151M, and phenol and methylated phenols were analyzed using USEPA method 8270SIM.

The additional analyses resulted in lower DLs for these compounds. However, for a few samples, the DLs for 1,2–dichlorobenzene, 1,2,4-trichlorobenzene, and 2,4-dimethylphenol still exceeded the SMS criteria. In addition, the DLs for benzyl alcohol and benzoic acid exceeded SMS criteria for five samples. Additional analyses could not be conducted for benzyl alcohol and benzoic acid to improve the elevated DLs reported using USEPA method 8270. The laboratory for this study (CAS) did not have an approved selective ion monitoring (SIM) method for benzyl alcohol and benzoic acid, as the toxicity levels are relatively high for these compounds, and a SIM method is normally not necessary.

A summary of the analytical chemistry results is provided in Appendix C. The analytical laboratory reports were accompanied by sufficient backup data and quality control (QC) results to enable independent reviewers to evaluate the quality of the data results (Chemical Data Report; Appendix D). Analytical data were reported in the units specified in Table 3.

Table 3. Analytical Method, Target Detection Limits, and SMS Chemical Criteria

Analyte	Method	TDL	WA SMS	WA SMS
			SQS	CSL
Conventional Parameters				
Total Solids	PSEP	0.1	–	–
Total Volatile Solids	PSEP	0.1	–	–
Total Organic Carbon	ASTM D4129-82M	0.1	–	–
Total Sulfides	9030B	1	–	–
Ammonia	SM 4500	1	–	–
Grain Size	PSEP-PS	---		
Metals		**mg/kg**	**mg/kg**	**mg/kg**
Arsenic	6010B/6020	19	57	93
Cadmium	6010B/6020	1.7	5.1	6.7
Chromium	6010B/6020	87	260	270
Copper	6010B/6020	130	390	390
Lead	6010B/6020	150	450	530
Mercury	7471A /245.5	0.14	0.41	0.59
Silver	6010B/6020	2	6.1	6.1
Zinc	6010B/6020	137	410	960
PAHs		**µg/kg**	**mg/kg TOC**	**mg/kg TOC**
Naphthalene	8270C/1625C	20	99	170
Acenaphthylene	8270C/1625C	20	66	66
Acenaphthene	8270C/1625C	20	16	57
Fluorene	8270C/1625C	20	23	79
Phenanthrene	8270C/1625C	20	100	480
Anthracene	8270C/1625C	20	220	1200
2-Methylnaphthalene	8270C/1625C	20	38	64
Fluoranthene	8270C/1625C	20	160	1200
Pyrene	8270C/1625C	20	1000	1400
Benzo(a)anthracene	8270C/1625C	20	110	270
Chrysene	8270C/1625C	20	110	460
Benzofluoranthenes	8270C/1625C	20	230	450
Benzo(a)pyrene	8270C/1625C	20	99	210
Indeno(1,2,3-c,d)pyrene	8270C/1625C	20	34	88
Dibenzo(a,h)anthracene	8270C/1625C	20	12	33
Benzo(g,h,i)perylene	8270C/1625C	20	31	78
Chlorinated		**µg/kg**	**mg/kg**	**mg/kg**

Analyte	Method	TDL	WA SMS	WA SMS
			SQS	CSL
Aromatics			**TOC**	**TOC**
1,4-Dichlorobenzene	8270C/1625C	3.2	3.1	9
1,2,4-Trichlorobenzene	8270C/1625C	6	0.81	1.8
Hexachlorobenzene	8081A	12	0.38	2.3
Phthalate Esters		**µg/kg**	**mg/kg TOC**	**mg/kg TOC**
Dimethyl phthalate	8270C/1625C	20	53	53
Diethyl phthalate	8270C/1625C	20	61	110
Di-n-butyl phthalate	8270C/1625C	20	220	1700
Butyl benzyl phthalate	8270C/1625C	20	4.9	64
Bis(2-ethylhexyl)phthalate	8270C/1625C	20	47	78
Di-n-octyl phthalate	8270C/1625C	20	58	4500
Ionizable Organic Compounds		**µg/kg**	**µg/kg**	**µg/kg**
Phenol	8270SIM	20	420	1200
2-Methylphenol	8270C/1625C	6	63	63
4-Methylphenol	8270SIM	20	670	670
2,4-Dimethylphenol	8270SIM	6	29	29
Pentachlorophenol	8151M	61	360	690
Benzyl alcohol	8270C/1625C	6	57	73
Benzoic acid	8270C/1625C	100	650	650
Miscellaneous Compounds		**µg/kg**	**mg/kg TOC**	**mg/kg TOC**
Dibenzofuran	8270C/1625C	20	15	58
Hexachlorobutadiene	8270C/1625C	20	3.9	6.2
N-Nitrosodiphenylamine	8270C/1625C	12	11	11
Total PCBs		**µg/kg**	**mg/kg TOC**	**mg/kg TOC**
	8082	**6**	**12**	**65**

Notes:

PAH polycyclic aromatic hydrocarbon

PCB polychlorinated biphenyl

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5.0 Results

This section presents the results of the Woodard Bay SPI and plan-view photography survey, subsurface sediment video probe survey, and surface and subsurface sediment chemistry results. A summary of results within the context of the project objectives is provided in Section 6.0.

5.1 SPI and Plan-View Photography

SPI photography was used to determine the horizontal extent of woody debris in surface sediments and assess the relative health of the benthic habitat. Plan-view images were used to supplement the SPI data to help determine the presence and extent of wood debris and to identify physical and biological surface features. The image analysis results for the SPI images are provided in Appendix A.

5.1.1 Surface Wood Debris Distribution

Using SPI and plan-view photography, wood debris visually identified in surface sediments (upper 20 cm) in the Project Area generally consisted of small pieces of weathered bark, wood pieces, or other small woody material. Fine wood fibers or pulp were not evident. A proportional estimate of wood debris (percent wood debris) was visually determined from the SPI images collected at each location (Figure 8). Overall, the SPI and plan-view images showed low wood debris content in surface sediments (range of 0 to 8 percent). Locations with the highest wood debris content (6 to 8 percent) included WB-06 in the North Storage Area, WB-17 and WB-18 in the Main Operational Area, and WB-03 in the South Storage Area (Figures 9 and 10). However, wood debris was not observed at the majority of locations sampled (73 percent of all locations sampled), including all nine locations sampled in the Chapman Bay Log Storage Area (Figure 8).

5.1.2 Grain Size Major Mode

The sediment grain size major mode, in phi units, was visually determined from the SPI images by comparison with grain size scales included in the image analysis software interface. The grain size comparator is a series of seven Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes): ≥ 4 phi (silt/clay), 4 to 3 phi (very fine sand), 3 to 2 phi (fine sand), 2 to 1 phi (medium sand), 1 to 0 phi (coarse sand), 0 to -1 phi (very coarse sand), and <-1 phi (gravels). The accuracy of this method has been documented by comparing SPI estimates with grain size statistics determined from laboratory sieve analyses (SAIC 1986).

Surface sediments at the majority of locations in the North Storage, Main Operational, and South Storage Areas consisted of homogeneous, tan and gray, water-rich silts and clays (≥ 4 phi) (Figure 11). The grain size distribution suggests that much of the Project Area is a depositional, low energy environment. Surface sediments in the Chapman Bay Log Storage Area consisted of tan-colored, very fine sands (4 to 3 phi) to fine sands (3 to 2 phi), suggesting a higher energy environment due to intertidal areas and shallower water depths. Fine sands and abundant shells were also observed at the mouth of Woodard Bay, near the base of the trestle (Figure 12) due to constricted (higher velocity) tidal flow in and out of the bay.

5.1.3 Apparent RPD Depth

The apparent RPD depth estimates the depth of oxygenation in the upper sediment column and can be considered the biological mixing depth by infaunal organisms. The upper surface of aerobic fine-grained sediments has a higher light reflectance value than underlying hypoxic or anoxic sediments. This is apparent in SPI images and is due to oxidized surface sediment that contains minerals in an oxidized state (typically an olive or tan color), while the reduced sediments below this oxygenated layer are generally gray or black. The apparent RPD depth provides an estimate of the biogenic sediment mixing depth because bioturbating organisms mix the oxidized sediment particles downward into the sediment column.

Apparent RPD depths had a range of 0.6 to 4.88 cm, with a mean of 2.83 cm throughout the Project Area (Figure 13). A gradient is visible from the north to the south, with relatively deep RPD depths (>3 cm) at 73 percent of the locations in the North Storage Area and 47 percent of the locations in the Main Operational Area. In these areas, several locations also appeared to show the presence of deeper, relict, or historical RPD signatures. This relict signature suggests that the RPD depths may vary during the season. For example, at WB-09 (replicate image E), the current RPD depth was measured at 4.52 cm and the interface is identified by the presence of a redish-tan color, likely related to the downward mixing of surface detritus (e.g., diatom or cyanobacteria on the surface, or recent phytoplankton detritus) by the resident infauna (Figure 12). A relict RPD depth is visible down to a depth of approximately 10 cm. Since the SPI survey was conducted during the month of February, the RPD depth may increase to a depth of 10 cm in the latter part of the year due to increased biological activity/mixing.

RPD depths range from 1.6 to 2.6 cm in the South Storage Area and three of the four locations (WB-03, WB-44, and WB-45) showed a high RPD contrast relative to the underlying anoxic sediments (Figure 10). High RPD contrast is often related to high inputs of organic-rich material (e.g., wood debris, dredged material, phytoplankton detritus), which increases sediment oxygen demand and results in more highly reduced sediments at depth. Shallow RPD depths (0.6 to 2.8 cm) were measured at a majority of locations in Chapman Bay and are likely due to the presence of compact coarse-grained sediments in this area and a higher rate of surface disturbance due to shallower water depths and tidal exchange.

5.1.4 Infaunal Successional Stage

Benthic infaunal communities generally follow a three-stage succession following a disturbance of the seafloor (Figure 15) (Pearson and Rosenberg 1978; Rhoads and Germano 1986). Stage I infauna are typically the first organisms to colonize the sediment surface. These opportunistic organisms may consist of small, tubicolous, surface-dwelling polychaetes. Stage II organisms are typically shallow-dwelling bivalves or tube-dwelling amphipods. Stage II communities are considered a transitional community before reaching Stage III, the high-order successional stage consisting of long-lived, infaunal deposit-feeding organisms. Stage III infauna consist of large, deep-burrowing infauna (e.g., maldanid and pectinid polychaetes, *Molpadia intermedia* sea cucumbers) that feed in a head-down orientation. This localized feeding activity results in distinctive excavations called "feeding voids." Diagnostic features of these feeding structures include a generally semicircular shape with a flat bottom and arched roof, and contain coarse sediment that are rejected by the infauna during the feeding process.

Although the abundance and diversity of the benthic community can only be determined through the collection and analysis of benthic infauna samples, the presence of Stage III benthic communities identified through the SPI survey are generally associated with healthy benthic habitat conditions. Conversely, the long-term degradation of the benthic environment frequently involves the loss of Stage III infauna and the dominance of pioneering Stage I infauna (Rhoads and Germano 1986). The Capitellid polychaetes are tolerant to pollution and a common Stage I organism. Capitellids are often one of the first groups to colonize an area recently impacted by dredged material disposal or an oil spill (Weiss 1995).

The distribution of infaunal successional stages in the Project Area is presented in Figure 16. Stage III or Stage I on III[1] communities were observed at 56 percent of the locations sampled. Stage III invertebrates that feed at depth in a head-down orientation create distinctive feeding voids visible in SPI images (Figure 17). Several locations also appeared to show the presence of collapsed feeding voids (Figure 18). Collapsed feeding voids are voids that are no longer active but still show evidence of coarse grain sediments or aggregates in the former void that are associated with selective feeding by the Stage III organism.

5.1.5 Organism-Sediment Index

The OSI provides a measure of general benthic habitat quality based on dissolved oxygen (DO) conditions, depth of the apparent RPD, infaunal successional stage, and presence or absence of sedimentary methane (Rhoads and Germano 1986). The OSI is a numerical index ranging from -10 to +11 (Table 4). The lowest OSI value is given to bottom sediments with low or no DO in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment. High OSI values are given to aerobic bottom sediments with a deep apparent RPD, mature macrofaunal community, and no methane gas. An OSI value of +6 or higher is generally considered indicative of undisturbed, healthy benthic habitat conditions.

The distribution of OSI values is presented in Figure 19. Mean OSI values ranged from +4 to +10 in the Project Area and an OSI value of +6 or greater was observed at 70 percent of the locations. Sedimentary methane was not observed at any of the locations. OSI values in the +4 to +5 range were measured in parts of the Chapman Bay Log Storage Area and in the nearshore areas around Weyer Point. However, it should be noted these areas generally have higher concentrations of sand and are located in shallow or intertidal areas. The OSI was developed for assessing general benthic habitat quality in soft-bottom subtidal sediments (Rhoads and German 1986) and may not accurately characterize habitat quality in sandy, intertidal sediments.

[1] Stage I taxa can persist, as they are opportunistic feeders and are commonly associated with Stage III community (Stage I on III) (Rhoads and Germano 1986).

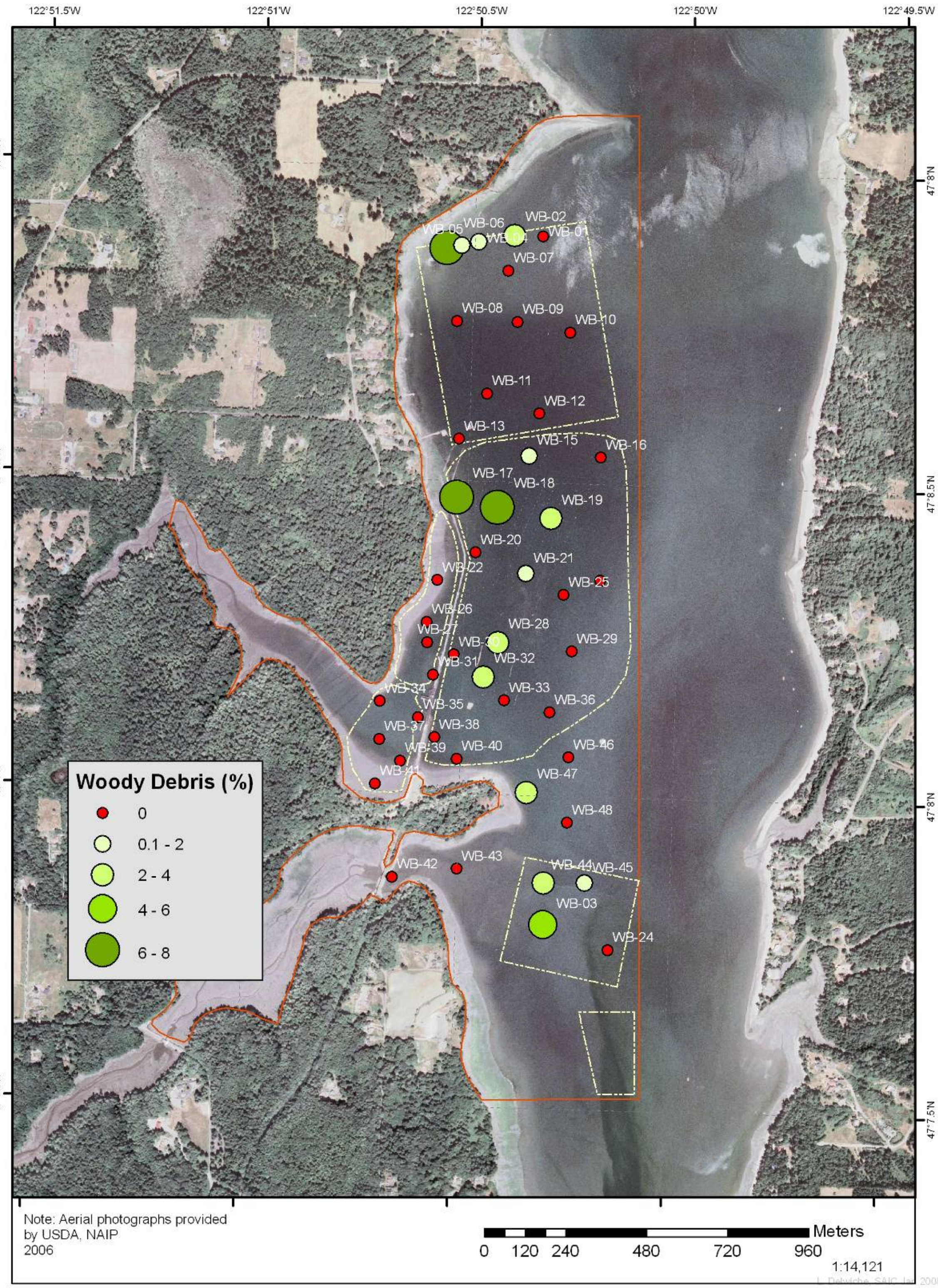


Figure 8. Distribution of Percent Woody Debris in Surface Sediments (< 20 cm) Determined from SPI Images

WB-06 (Plan-View Image)

WB-06/Replicate B (SPI Image)

Figure 9. Plan-View and SPI Images from Location WB-06

The plan-view image shows scattered bark pieces and shell particles on the sediment surface. The bark pieces are generally less than 1cm in length. The SPI image shows moderate amounts of wood and bark pieces (approximately 10 percent) and shell particles on the sediment surface, with reduced sediment conditions at depth.

WB-18/A

WB-03/C

Figure 10. SPI Images from WB-18/A and WB-03/C

Sampling locations WB-18 (Main Operational Area) and WB-03 (South Storage Area) appeared to show the presence of degraded wood or bark pieces in the upper portion of the sediment column (approximately 10 percent for both images). Brown diatom or cyanobacteria cover is visible on the sediment surface, and scattered shell particles are present at depth.

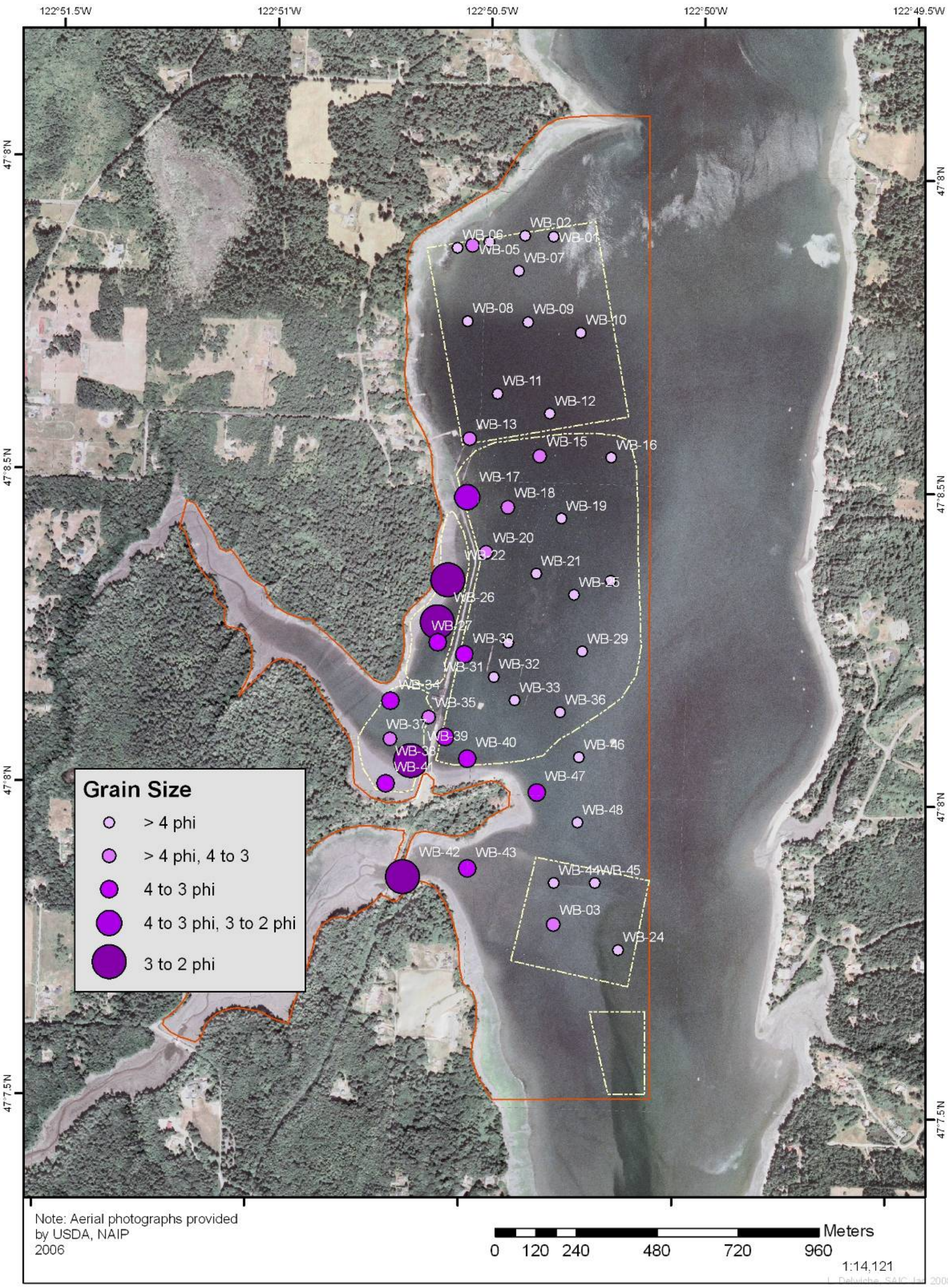
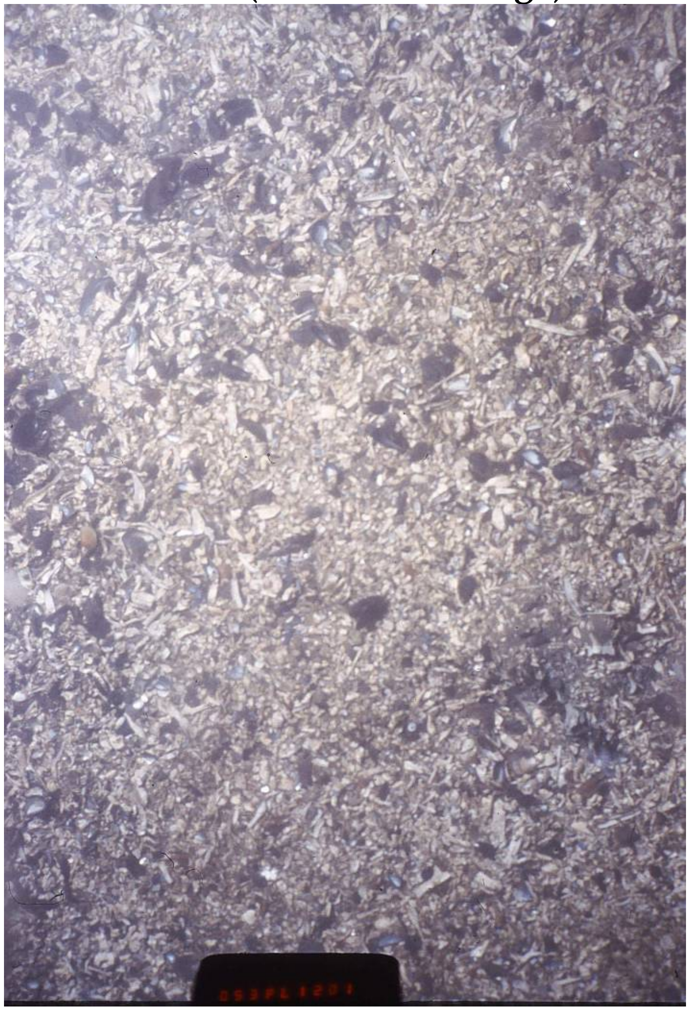


Figure 11. Surface Sediment Grain Size Major Mode (in phi Size) Determined from SPI Images

WB-42 (Plan-View Image)



WB-42/C (SPI Image)

Figure 12. Plan-View and SPI Images from Location WB-42 Near the Mouth of the Woodard Bay Trestle

The plan-view and SPI images show the presence of abundant shell debris below the Woodard Bay trestle. The shell debris originates from barnacle and mussel growth on the trestle. A large seastar (*Pisaster* sp.) is visible in the SPI image.

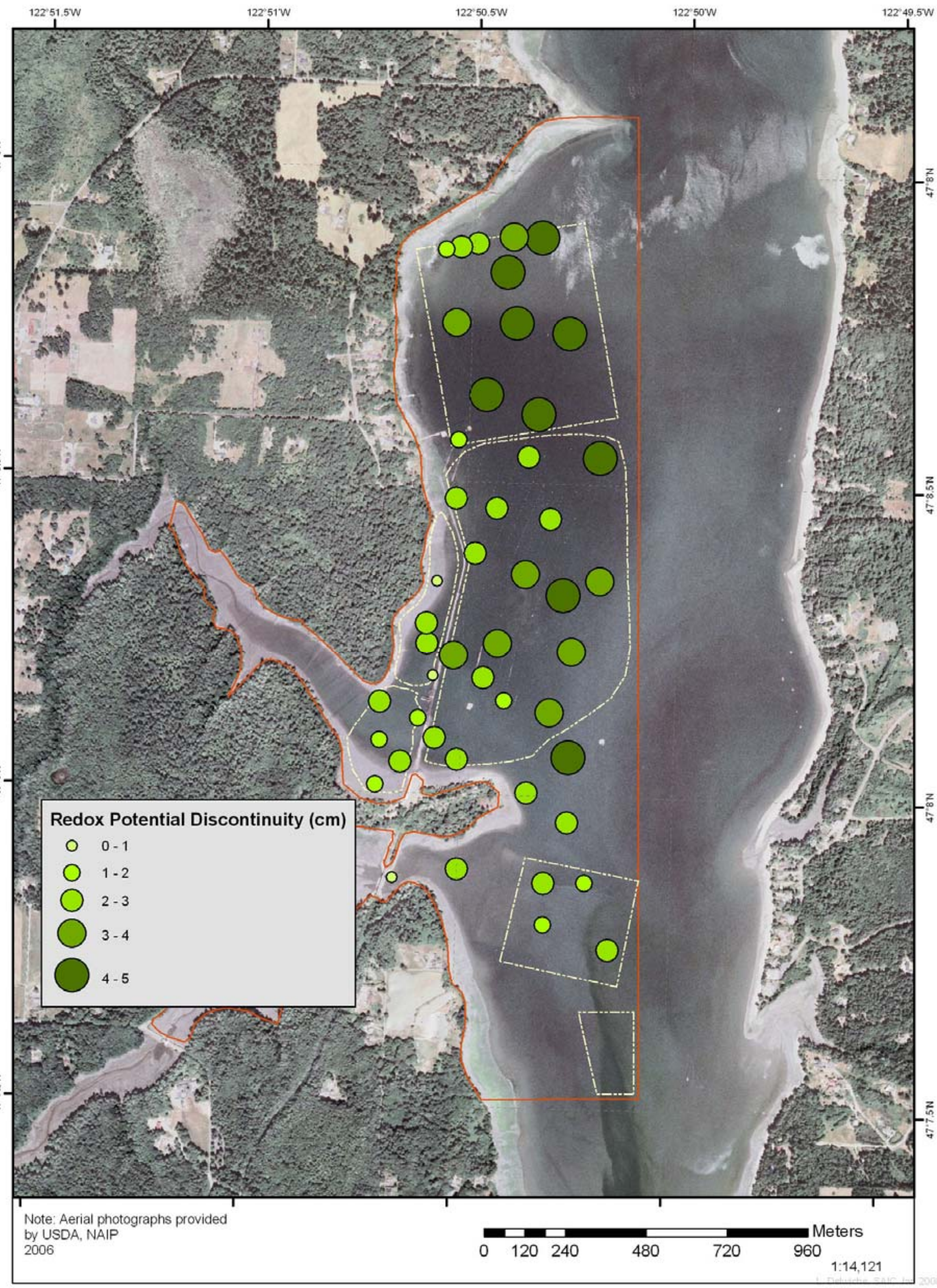


Figure 13. Apparent RPD Depths Determined from SPI Images

WB-09 (Plan-View Image)

WB-09/E (SPI Image)

Figure 14. Plan-View and SPI Images from Location WB-09 in the North Storage Area

The plan-view image shows a brownish colored diatom or cyanobacteria surface coating with scattered surface tubes, presumed to be bamboo worm (Maldanid) polychaetes. The current RPD depth in the SPI image was measured at 4.52 cm and the interface is identified by the presence of redish-tan colored sediment, likely related to the downward mixing of surface detritus by the resident infauna. A relict RPD depth is visible down to a depth of approximately 10 cm.

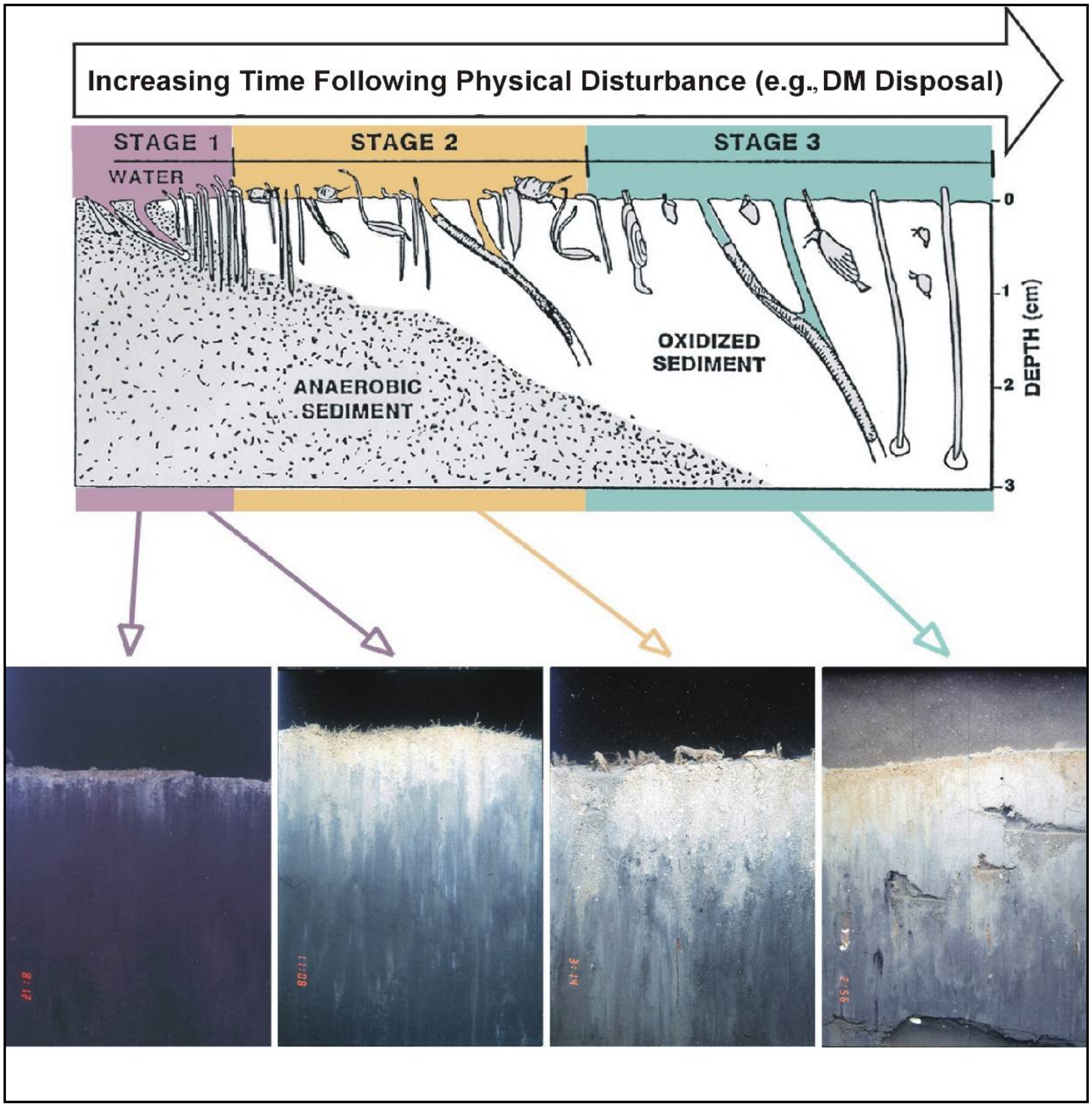


Figure 15. Idealized Development of Infaunal Succession Stages Over Time Following a Physical Disturbance with Example SPI Images

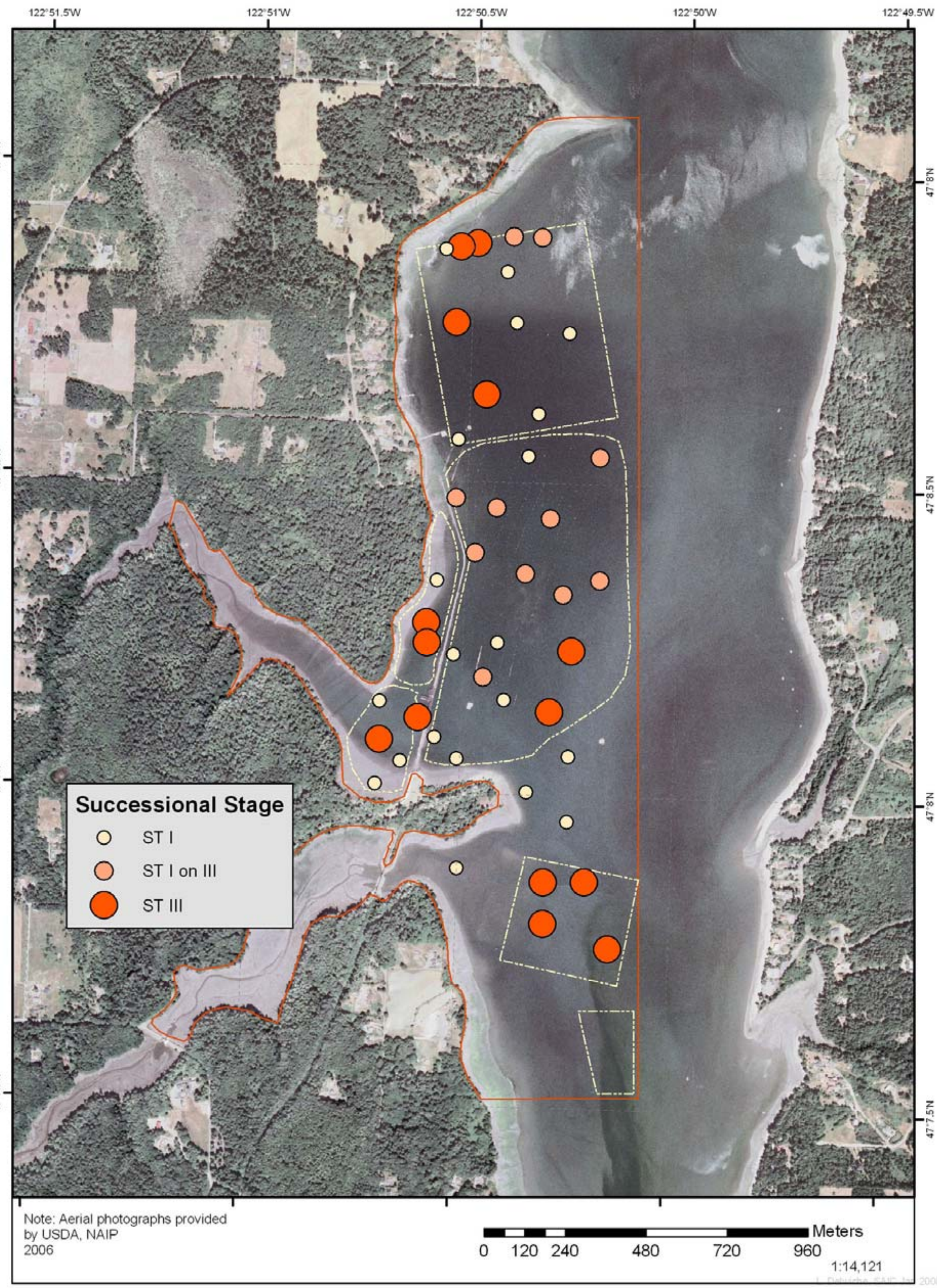


Figure 16. Distribution of Infaunal Successional Stage Determined from SPI Images

WB-29 (Plan-View Image)

WB-29/A (SPI Image)

Figure 17. Plan-View and SPI Images from Location WB-29 in the Main Operational Area

The plan-view image shows a brownish colored diatom or cyanobacteria surface coating with surface tubes presumed to be bamboo worm (Maldanid) polychaetes. A small sea pen is present near the top of the image (arrow). A large feeding void, evidence of a head-down deposit feeding Stage III organism, is visible in the SPI image (arrow).

WB-11/C WB-46/A

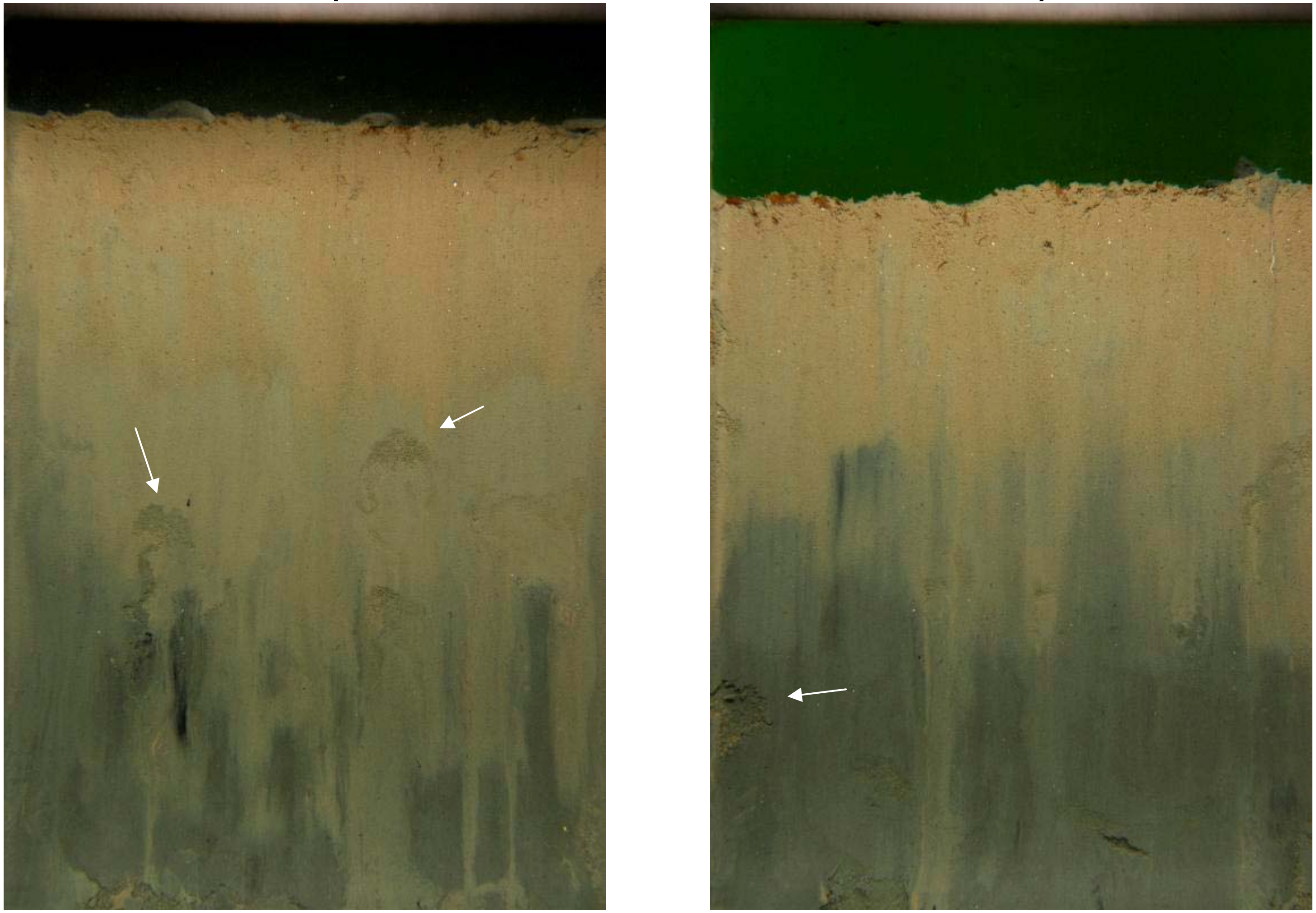


Figure 18. SPI Images from WB-11/C and WB-46/A

Locations WB-11 (North Storage Area) and WB-46 (just south of Main Operational Area) show well-developed apparent RPD depths and the presence of collapsed feeding voids (arrows). Collapsed feeding voids are no longer active but still show evidence of coarse grain sediments or aggregates in the former void that are associated with selective feeding by the Stage III organism.

Table 4. Calculation of the Organism-Sediment Index

Choose One Value:	
Mean RPD Depth Classes	**Index Value**
0.00 cm	0
>0 – 0.75 cm	1
0.76 – 1.50 cm	2
1.51 – 2.25 cm	3
2.26 – 3.00 cm	4
3.01 – 3.75 cm	5
>3.75 cm	6
Choose One Value:	
Successional Stage	**Index Value**
Azoic	- 4
Stage I	1
Stage I - II	2
Stage II	3
Stage II – III	4
Stage III	5
Stage I on III[1]	5
Stage II on III[1]	5
Choose One or Both if Appropriate:	
Chemical Parameters	**Index Value**
Methane Present	- 2
No/Low Dissolved Oxygen[2]	- 4
Organism – Sediment Index =	**Total of Above Subset Indices (Range: - 10 + 11)**

Notes:

1. Stage I taxa can persist, as they are opportunistic feeders and are commonly associated with Stage III community (Rhoads and Germano 1986). Similarly, in the transition from Stage II to Stage III both taxa can be present resulting in a Stage II or III classification.

2. No/low dissolved oxygen is based on the imaged evidence of reduced, low reflectance (i.e., high oxygen demand) sediment at the sediment-water interface. It is not a chemical measurement using Winkler titration or polargraphic electrode.

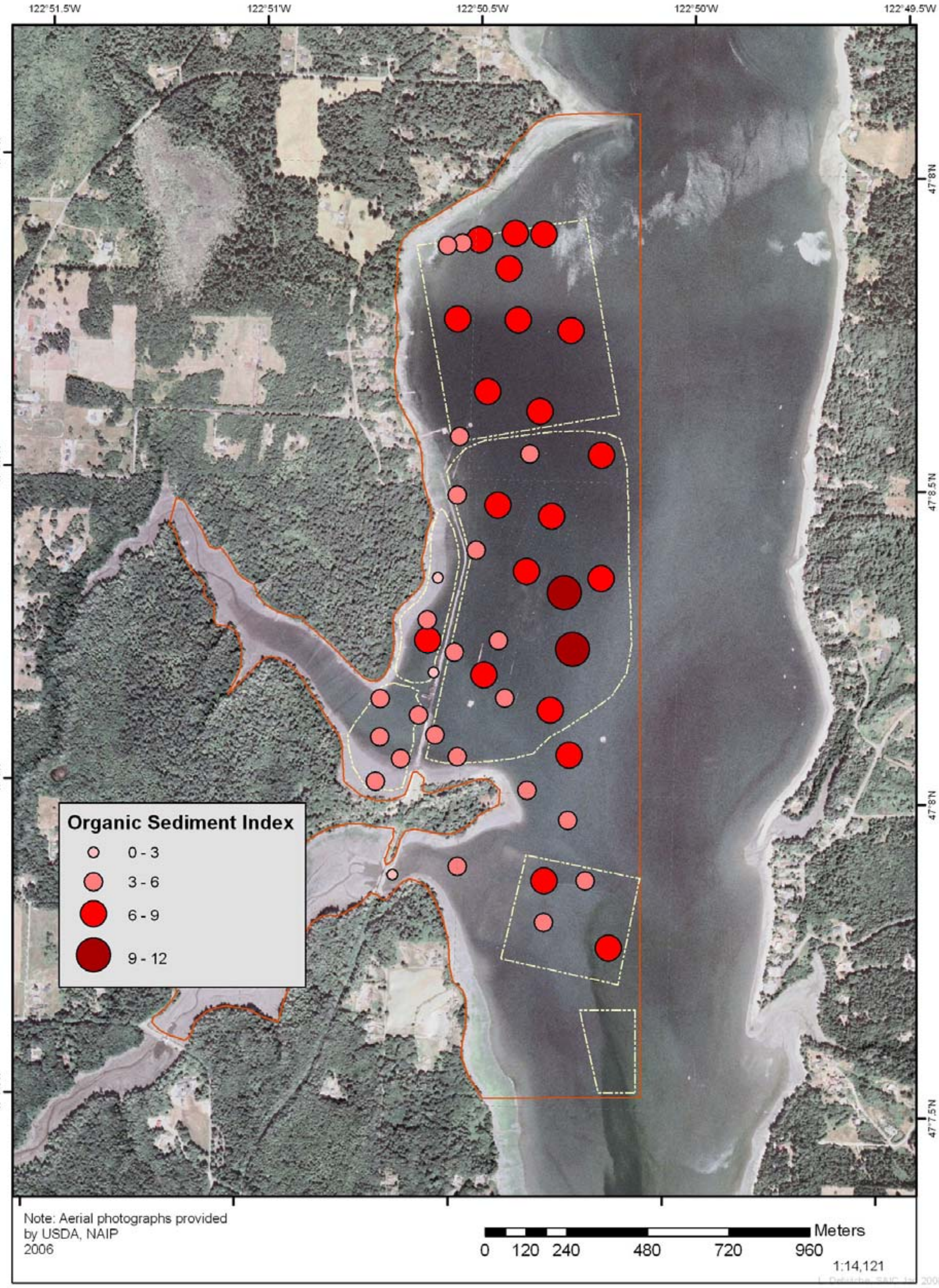


Figure 19. Distribution of OSI Values in the Project Area

5.2 Subsurface Sediment Video Probe

Video probe data were used to determine the vertical extent of woody debris in the upper 6 feet of the sediment column. Video probes were conducted at 48 different locations throughout the four investigation areas (Figure 4). Percent wood debris (proportional estimate) was determined for each 0.5-foot interval and data plots are provided in Appendix B. The North Storage Area had the greatest average amount of woody debris (average of 8.1 percent), followed by the Main Operational Area (7.0 percent), Chapman Bay Log Storage Area (5.6 percent), and South Storage Area (2.2 percent) for all depth intervals sampled in each area. Average percent woody debris was determined for the entire video probe (0 to 6 feet), unless specified otherwise below. Woody debris was generally absent or sparse in the upper 1.0 foot of the sediment column, which is generally consistent with the findings of the SPI survey (see Figure 8).

Within all areas except the Chapman Bay Log Storage Area, a greater amount of woody debris was found in the upper 3 feet of the sediment column than the 3- to 6-foot interval. At the Chapman Bay Log Storage Area, wood debris was slightly higher in the 3- to 6-foot interval (6.9 percent) than the upper 3 feet (4.0 percent).

5.2.1 North Storage Area

Sediment video probes were conducted at 13 locations within the North Storage Area. Woody debris found in the upper 6 feet of the sediment column (0.5-foot intervals) ranged from 0 to 100 percent, with an average of 8.1 percent. Sampling location WB-09 had the greatest average percentage of woody debris (32 percent), with a small log or branch encountered between 2.0 and 3.0 feet below mudline. The lowest amount of woody debris was observed at WB-11 (0.9 percent, consisting of small (0.5 to 1.5 cm) wood fragments. At all but one location, the upper 3 feet of sediment contained a greater amount of woody debris (13 percent) than the 3- to 6-foot interval (4.3 percent).

5.2.2 Main Operational Area

Sediment video probes were conducted at 17 locations within the Main Operational Area. Woody debris found in the upper 6 feet of the sediment column ranged from 0 – 75 percent, with an average of 7.0 percent. Sampling locations WB-18 and WB-20, located near the northern portion of the Chapman Bay pier, had the greatest average percentage of woody debris (29 and 25 percent, respectively) consisting of abundant small to large wood and bark fragments. No woody debris was observed at WB-16 in central Henderson Inlet. In general, the upper 3 feet of sediment contained a greater amount of woody debris (8.9 percent) than the 3- to 6-foot interval (5.1 percent).

5.2.3 Chapman Bay Log Storage Area

Sediment video probes were conducted at eight locations within the Chapman Bay Log Storage Area. Woody debris found in the upper 6 feet of the sediment column ranged from 0 to 100 percent, with an average of 5.6 percent. The sampling locationWB-41, located in the southern most portion of the log storage area, had the greatest average percentage of woody debris (21 percent), with a small log encountered at 2.0 feet below mudline and abundant small peat-like particles encountered from 3.5 to 4.5 feet below mudline. The least woody debris was observed at WB-27 (0.4 percent) consisting of small, loose wood fragments at 6.0 feet below mudline. In general, the 3- to 6-foot interval of sediment contained a greater amount of woody debris (6.9 percent) than the upper 3 feet (4.0 percent).

5.2.4 South Storage Area

Sediment video probes were conducted at 10 locations within the South Storage Area. Woody debris found in the upper 6 feet of the sediment column ranged from 0 – 30 percent, with an average of 2.2 percent. The sampling location WB-03 had the greatest average percentage of woody debris (8.3 percent), consisting of scattered wood fragments primarily between 0.5 to 1.5 feet below mudline. No woody debris was observed at locations WB-46 and WB-48. In general, the upper 3 feet of sediment contained a greater amount of woody debris (2.9 percent) than the 3 to 6 foot interval (1.6 percent).

5.3 Evaluation of Woody Debris in Sediment Cores

Ten subsurface sediment cores were collected to visually confirm estimates of subsurface wood debris accumulation made with the video probe, as well as for chemical testing to determine whether chemical contaminants exceed SMS criteria (Sections 5.4 and 5.5). The sediment core logs can be found in the Cruise Report (SAIC 2008b).

Wood debris measured by the video probe was generally confirmed by the sediment cores (Figure 20). In general, the distribution of woody debris matched between the two methods with the exception of a few comparisons (e.g., WB-31, and WB-38). Sources of variability such as spatial heterogeneity, differences in visual identification, and differences in the observed diameter of area (1.5 inch diameter video probe versus 3.5 inch core barrel), may account for discrepancies between the two methods of estimating woody debris in nearby locations. A calculation of confidence intervals between the video probe and sediment core data is provided in Appendix E. Woody debris in the upper 6 feet of the sediment cores ranged from 0 to 75 percent. Wood debris consisted primarily of fibers and small pieces of wood or bark. Cores WB-18 and WB-38 had the greatest total amount of woody debris, while almost no woody debris was observed at location WB-43 near the mouth of Woodard Bay. Generally for all locations, the upper 3 feet of sediment contained a greater amount of woody debris than the lower 3 feet (3- to 6-foot interval), similar to what was observed with the video probe.

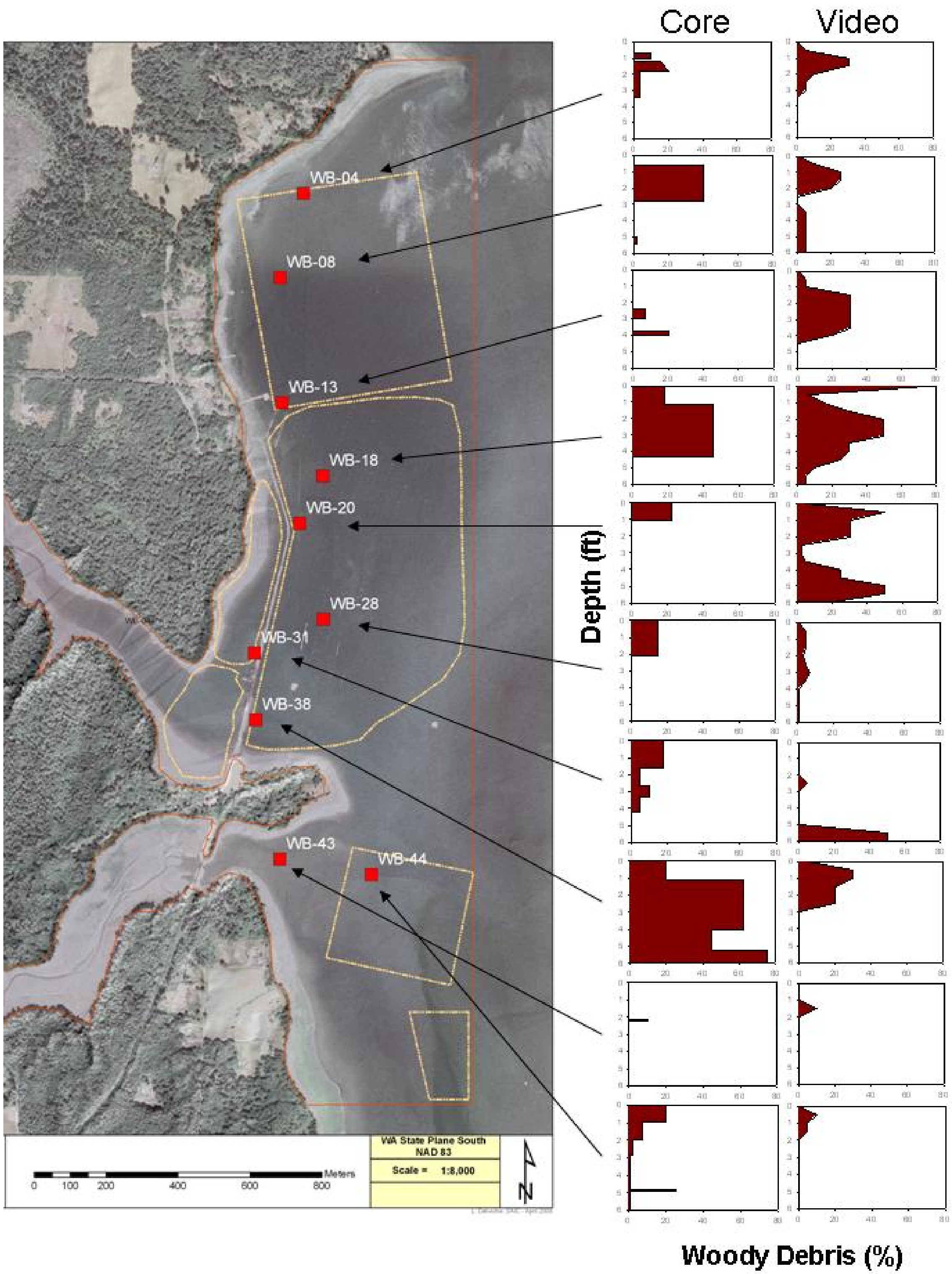


Figure 20. Comparison of Percent Woody Debris Measured in Subsurface Sediment Cores and Co-located Video Probes

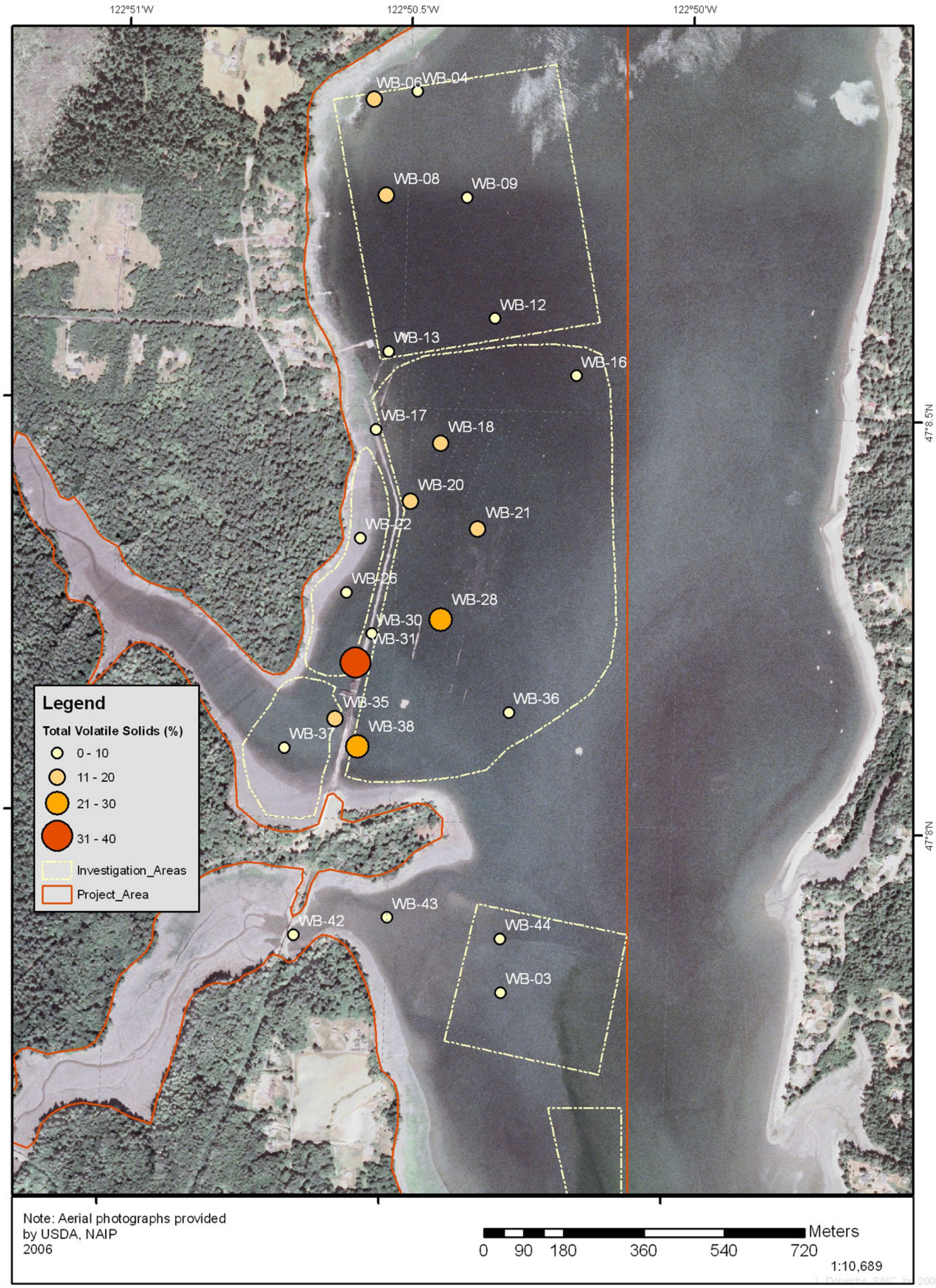


Figure 21. Percent Total Volatile Solids in Surface Sediments

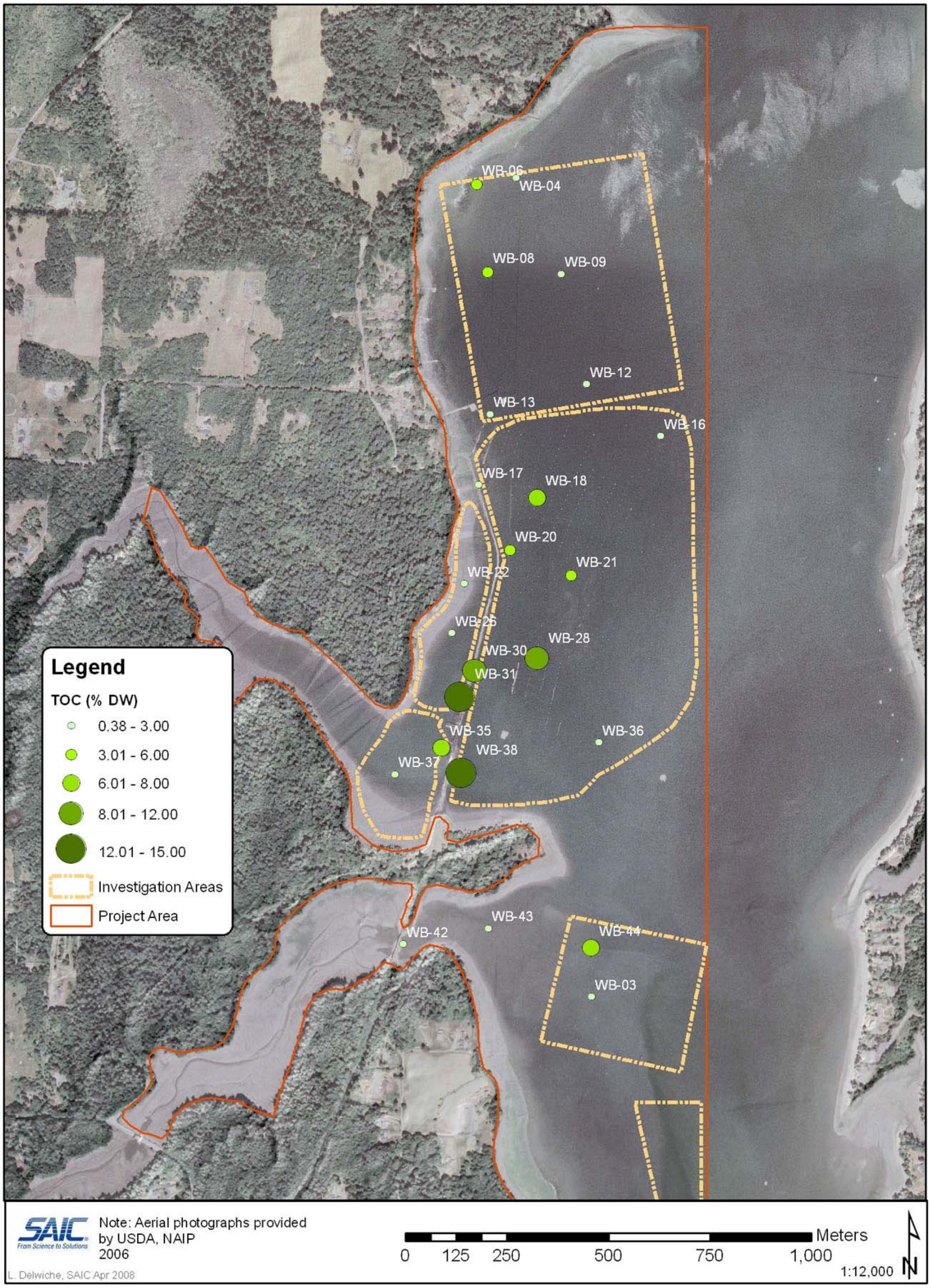


Figure 22. Percent TOC in Surface Sediments

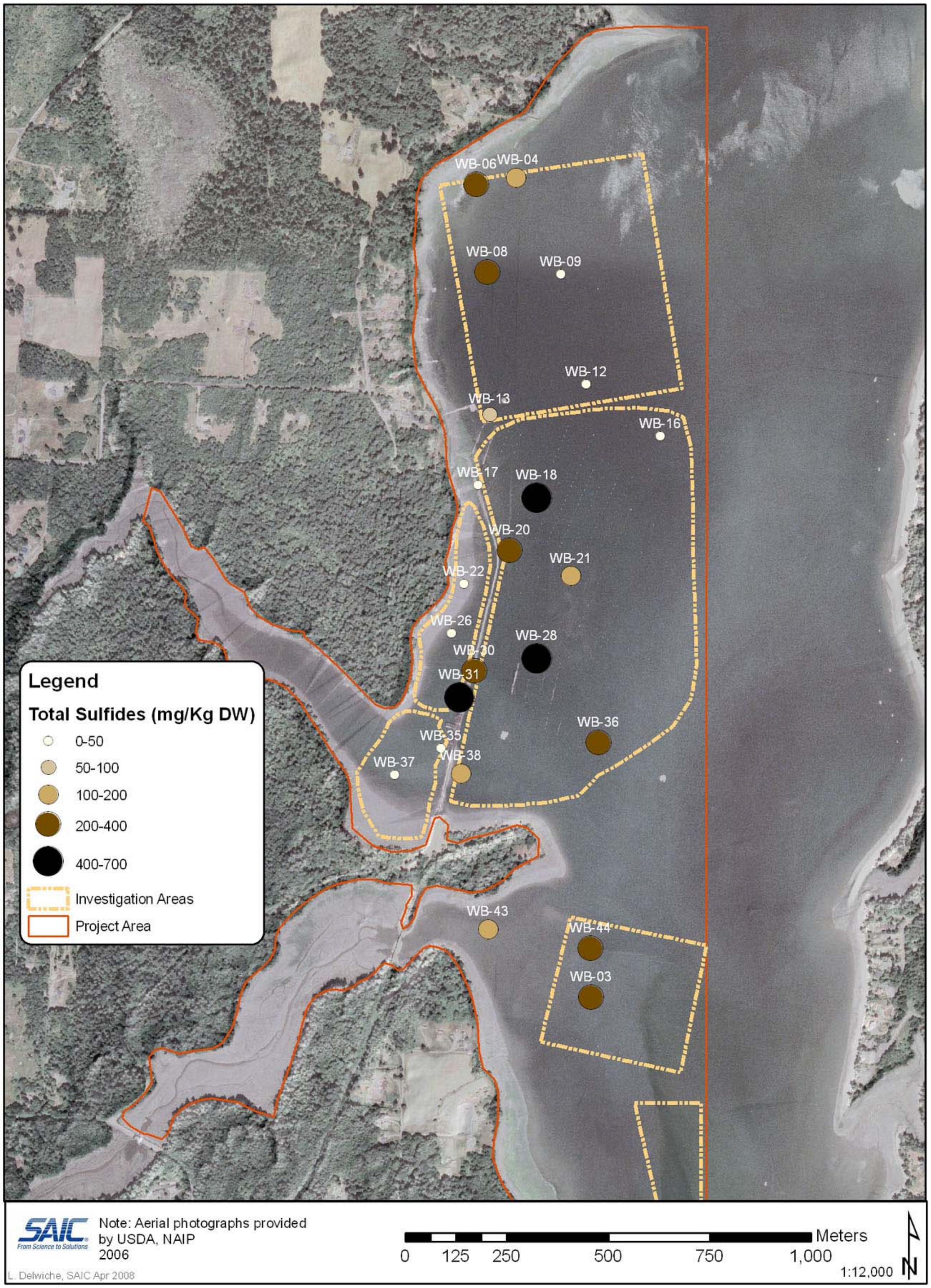


Figure 23. Distribution of Total Sulfides in Surface Sediments

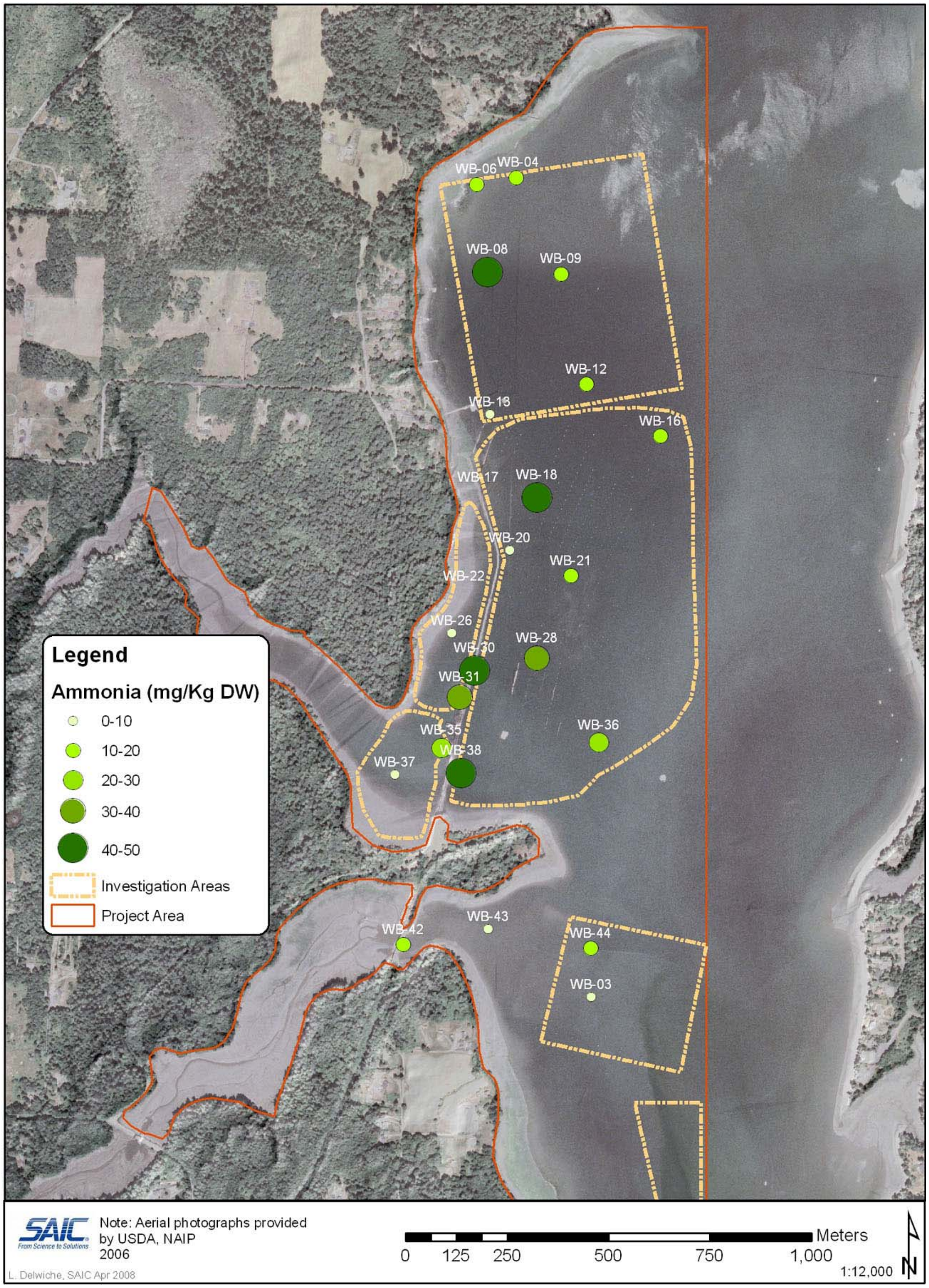


Figure 24. Distribution of Ammonia in Surface Sediments

5.4 Surface Sediment Chemistry

Surface sediment samples (0 to 1 feet) were collected from both grab samples (14 locations) and sediment cores (10 locations). Surface sediment samples were analyzed for sediment conventional parameters and the SMS chemicals of concern (Figure 5). The SMS chemical results are evaluated relative to the SMS SQS and the CSLs, as well as the spatial distribution of the contaminants. The SMS does not specify standards for sediment conventional parameters. Data completeness and validation results are discussed in the Chemical Data Report (Appendix D).

5.4.1 Sediment Conventional Parameters

Sediment conventional parameters include grain size, total solids, total volatile solids (TVS), TOC, total sulfides, and ammonia. Grain size distribution in the Project Area varied between the areas of interest. The Main Operational Area and North Storage Area had the highest silt content, while the sediments with the highest sand content were generally found in the Chapman Bay and South Storage Areas.

TOC, TVS, total sulfides, and ammonia are conventional parameters that can be elevated in sediments due to the degradation of wood debris. The biological oxygen demand associated with the degradation of wood waste can cause a build up of electrochemically reduced chemical species such as sulfides, ammonia, and methane (Hansen et al. 1971; Conlan and Ellis 1979; Freese and O'Clair 1987). Elevated levels of sulfides and ammonia in sediments can cause toxicity to benthic organisms. As noted previously, methane gas bubbles were not observed in surface sediments during the SPI survey (Section 5.1). TVS provides a measure of the organic fraction of the sediment, which is likely correlated to the amount of woody debris in the sediment (Kendall and Michelsen 1997). However, the Dredged Material Management Program (DMMP) specifies that dredged material containing an organic fraction greater than 25 percent dry weight requires biological testing to assess the suitability of the material for open-water disposal (Kendall and Michelsen 1997).

The highest concentrations of sulfides, ammonia, TVS, and TOC are generally found in proximity to the Chapman Bay Pier and sites of wood debris accumulation (Figures 21 to 24 and Appendix B). Sediment conventional results are summarized in Table 5. A summary of conventional parameters by project area is provided below.

Table 5. Surface Sediment Conventional Parameter Summary

Study Area	Summary Statistic	# of Samples	Total Solids (%)	Station ID	TVS (%)	Station ID	TOC (%)	Station ID	Ammonia (mg-N/kg)	Station ID	Sulfides (mg/kg)	Station ID
Main Operational Area	**Min**	9	33.3	WB-18	2.97	WB-17	1.1	WB-17	4.1	WB-17	1.1	WB-16
	Max		69.3	WB-17	29.3	WB-28	12.1	WB-38	46.2	WB-30	699.0	WB-18
	Average		43.6		14.2		6.3		25.8		245.8	
Chapman Bay Log Storage Area	**Min**	5	34.0	WB-31	1.6	WB-22	0.4	WB-22	4.2	WB-22	0.7	WB-37
	Max		75.6	WB-22	33.5	WB-31	14.4	WB-31	33.5	WB-31	463.0	WB-31
	Average		55.4		10.4		5.3		16.1		106.4	
North Storage Area	**Min**	6	34.6	WB-12	4.21	WB-04	1.6	WB-13	5.7	WB-13	4.1	WB-12
	Max		61.9	WB-04	23.1	WB-08	6.0	WB-08	47.4	WB-08	365.0	WB-08
	Average		46.2		10.5		3.3		19.1		156.1	
South Storage Area	**Min**	4	57.2	WB-03	2.33	WB-43	0.7	WB-43	6.5	WB-43	0.8	WB-42
	Max		73.1	WB-43	8.19	WB-44	6.4	WB-44	16.4	WB-42	283.0	WB-03
	Average		63.5		5.2		2.6		10.9		176.7	

North Storage Area

Silt and sand made up the largest fraction of the grain size distribution in most of the samples from the North Storage Area. Sand was less prevalent at the deepest locations (WB-09 and WB-12), where silt was 62 percent of the total grain size, followed in abundance by percent clay (28 percent). Percent TOC and total sulfide values for the region averaged 3.3 ± 1.9 percent and 156 ± 159 mg/kg, respectively, with the highest values found at locations WB-06 and WB-08 in the most northwest extent of the North Storage Area. The highest TVS values were also measured at WB-06 and WB-08 (12.2 and 23.1 percent, respectively).

Main Operational Area

The silt content of the Main Operational Area sediments was highest in the central portions of the Henderson Inlet embayment. At these locations, silt was 36 to 65 percent of the total grain size, followed in abundance by percent clay ranging from 16 to 28 percent. The locations along the eastern edge of Chapman Bay Pier, including WB-17, WB-20, WB-30, and WB-38, were mostly sand, with fractions ranging from 36 to 89 percent. Gravel made up the next largest fraction at these sites ranging between 2 and 45 percent. Percent TOC values varied greatly throughout the region (1 to 12 percent), with values greater than 8 percent at core locations in close proximity to the pier. Locations WB-18, WB-30, and WB-38, in close proximity to the pier, had elevated ammonia values averaging 44 ± 2.3 mg/kg, versus 22 ± 8.0 mg/kg for more easterly locations. TVS and total sulfide values generally showed a similar distribution, with the highest concentrations measured at stations WB-18, WB-28, and WB-38. TVS values averaged 25.2 ± 8.9 percent at these three locations, versus 8.7 ± 3.1 percent at the other locations, and total sulfides averaged 420 ± 300 mg/kg at these three locations, versus 159 ± 130 mg/kg at the other locations in the Main Operational Area.

Chapman Bay Log Storage Area

Sediments in the Chapman Bay Log Storage Area were dominated by sands, with nearshore locations WB-22 and WB-26 containing 70 percent and 90 percent sand, respectively. Silts constitute up to 41 percent of the deeper stations in the mouth of Chapman Bay. The two locations on the immediate western flank of Chapman Bay Pier (WB-31 and WB-35) had high TOC values (14.4 and 8 percent, respectively), while other locations within the Log Storage Area averaged 1.3 ± 0.8 percent. TVS was also high at WB-31 and WB-35 (33.5 and 18.4 percent, respectively) versus the other stations (average of 3.9 ± 2.0 percent). Ammonia and total sulfide values varied considerably for the region, with location WB-31 having the greatest concentration of both ammonia and total sulfides.

South Storage Area

Sediments from the South Storage Area were dominated by the sand grain size fraction (63–87 percent). Silt was the secondary size fraction, with the exception of location WB-42 in close proximity to the Woodard Bay trestle, where gravel was secondary. TOC values encompassed a wide range from 0.7 to 6.4, with the greatest concentration at location WB-44 in Henderson Inlet. TVS, total solids, and ammonia were similar throughout the area. However, sulfides increased in concentration from 0.8 to 283 mg/kg from east to west.

5.4.2 SMS Chemistry

A total of 24 surface samples were analyzed for the SMS chemicals of concern. All detected chemical compounds were below the SQS criteria, with the exception of five samples that exceeded the SQS criteria for phenol in the North Storage Area and Main Operational Area[2], and one field duplicate sample in the South Storage Area (Table 6; see Appendix C). All metals were detected well below the SQS criteria. The miscellaneous extractable compounds and PCBs were undetected at all locations. PAH compounds and benzoic acid were detected at locations near the Chapman Bay Pier, although at concentrations below the SQS criteria. Phenol concentrations in excess of SQS criteria were generally found in central Henderson Inlet. The distribution of detected concentrations of total LPAH, total HPAH, phenol (8270 and 8270SIM results plotted separately), and benzoic acid are provided in Figures 25 through 29. A summary of SMS chemistry results by project area is provided below.

The DL for a few undetected chemicals exceeded the SQS or CSL criteria (Table 6). The DL of chemicals that exceeded the SMS numeric criteria in surface sediments included: 2,4-dimethylphenol in 7 of 24 samples (29 percent), 1,2,4-trichlorobenzene in 4 of 24 samples (17 percent), both benzyl alcohol and benzoic acid in the same 3 of 24 samples (13 percent), and 1,2-dichlorobenzene in 1 of 24 samples (4 percent).

North Storage Area

All detected chemicals of concern in surface sediments were relatively low in the North Storage Area, with only two locations found to have concentrations measured above the SQS criteria. The highest total HPAH concentration was measured at WB-06 (11.5 mg/kg TOC), well below the SQS criterion of 960 mg/kg TOC (Figure 26). Benzoic acid was measured from a low of 130 µg/kg DW (WB-08) to a high of 230 µg/kg DW (WB-12), also below the SQS criterion of 650 µg/kg DW (Figure 29). Phenol was measured at stations WB-09 and WB-12 (using the 8270SIM method) with concentrations of 780 and 1400 µg/kg DW, respectively, above the SQS criteria of 420 µg/kg DW (Figure 27). Under the original USEPA method 8270 results, stations WB-09 and WB-12 had phenol concentrations of 434 and 56 µg/kg DW, respectively, which is below the SQS criteria (Figure 28).

The compound 2,4-dimethylphenol was undetected in all samples, but the DLs slightly exceeded the SQS and CSL criteria for locations WB-08 and WB-12. In addition, 1,2,4-trichlorobenzene, benzyl alcohol, and benzoic acid were undetected at station WB-06, but DLs also exceeded SQS and CSL criteria. Elevated DLs were reported for these compounds due to matrix interference problems encountered during the laboratory analysis (USEPA method 8270). However, it should be noted that 1,2,4-trichlorobenzene, benzyl alcohol, and benzoic acid were also undetected at station WB-04 (located just east of WB-06) and DLs were well below the SQS criteria for those compounds.

[2] The five samples originally did not exceed SQS criteria for phenol based on the initial semi-volatile organic compound analysis using USEPA Method 8270. To address elevated detection limits for some samples, phenols and methylated phenols were reanalyzed using USEPA Method 8270SIM. Higher concentrations of phenol were measured during the reanalyses (see Section 6.2).

Table 6. Surface Sediment Chemistry that Exceeds SMS Guideline Values

			North Storage Area							
Station Number	**WA SMS SQS**	**WA SMS CSL**	**WB-06-S**	**Q**	**WB-09-S**	**Q**	**WB-12-S**	**Q**	**WB-08-C0-1**	**Q**
Chlorinated Aromatics in mg/kg TOC										
1,2-Dichlorobenzene	2.3	2.3								
1,2,4-Trichlorobenzene	0.81	1.8	2.1	U						
Ionizable Organic Compounds in ug/kg DW										
Phenol	420	1200			780		1400			
2-Methylphenol	63	63								
2,4-Dimethylphenol	29	29					29	U	31	U
Benzyl Alcohol	57	73	220	U						
Benzoic Acid	650	650	2200	U						

			Main Operational Area											
Station Number	**WA SMS SQS**	**WA SMS CSL**	**WB-16-S**	**Q**	**WB-17-S**	**Q**	**WB-30-S**	**Q**	**WB-36-S**	**Q**	**WB-18-C0-1**	**Q**	**WB-28-C0-1**	**Q**
Chlorinated Aromatics in mg/kg TOC														
1,2-Dichlorobenzene	2.3	2.3												
1,2,4-Trichlorobenzene	0.81	1.8			0.9	U								
Ionizable Organic Compounds in ug/kg DW														
Phenol	420	1200	880				710		660					
2-Methylphenol	63	63												
2,4-Dimethylphenol	29	29									29	U	30	U
Benzyl Alcohol	57	73					82	U						
Benzoic Acid	650	650					820	U						

Notes:

Q Laboratory Qualifier

U Undetected

Table 6. Surface Sediment Chemistry that Exceeds SMS Guideline Values (continued)

			Log Storage Area						South Storage Area			
Station Number	WA SMS	WA SMS	WB-22-S	Q	WB-35-S	Q	WB-31-C0-1	Q	WB-03-D	Q	WB-43-C0-1	Q
	SQS	CSL										
Chlorinated Aromatics in mg/kg TOC												
1,2-Dichlorobenzene	2.3	2.3	2.6	U								
1,2,4-Trichlorobenzene	0.81	1.8	2.6	U					1.4	U	1.5	U
Ionizable Organic Compounds in ug/kg DW												
Phenol	420	1200							530	D		
2-Methylphenol	63	63										
2,4-Dimethylphenol	29	29			29	U	29	U				
Benzyl Alcohol	57	73					150	U				
Benzoic Acid	650	650					1500	U				

Notes:

Q Laboratory Qualifier

U Undetected

Main Operational Area

All detected chemicals of concern measured in surface sediments were below the SQS criteria in the Main Operational Area, with the exception of three locations where phenol exceeded the SQS. Slightly elevated concentrations of total low molecular weight PAHs (LPAHs)and high molecular weight PAHs (HPAHs) were measured at locations WB-17 and WB-30 near the Chapman Bay Pier, but well below the SQS criteria for these compound groups (Figures 25 and 26). The highest phenol concentration (8270SIM method) in the Main Operational Area was detected at WB-16 (880 µg/kg DW), above the SQS criterion of 420 µg/kg DW (Figure 27). Locations WB-30 and WB-36 also had detected phenol values (710 and 660 µg/kg DW, respectively) that exceeded the SQS criteria. Under the original USEPA method 8270 results, the phenol concentrations at these locations were below the SQS criteria (Figure 28). As in the North Storage Area, 2,4-dimethylphenol was undetected in all samples, but the DLs exceeded the SQS and CSL criteria at locations WB-16, WB-18, and WB-28. At sampling location WB-17, 1,2,4-trichlorobenzene was undetected and the DL (0.9 U mg/kg TOC) slightly exceeded the SQS criterion of 0.81 mg/kg TOC. At sampling location WB-30, benzyl alcohol and benzoic acid were also undetected but the DL exceeded SQS and CSL criteria.

Chapman Bay Log Storage Area

All detected chemicals of concern measured in surface sediments were below the SQS criteria in the Chapman Bay Log Storage Area. Slightly elevated concentrations of total HPAHs were measured at locations WB-22, WB-31, and WB-37, but concentrations were well below the SQS criterion (Figure 26). The highest phenol concentration (150 µg/kg DW) was measured at station WB-28, below SQS criteria (Figure 27). Nearby at station WB-31, benzoic acid was undetected by the DL (1500 µg/kg DW), exceeded the SQS criteria (Figure 29). As in the other project areas, 2,4-dimethylphenol was undetected in all samples, but the DLs were at the SQS and CSL criteria at stations WB-31 and WB-35. At sampling location WB-22, 1,2-dichlorobenzene and 1,2,4-trichlorobenzene were undetected but the DLs exceeded the SQS and CSL criteria. Similar to location WB-30 in the Main Operational Area, benzyl alcohol and benzoic acid were undetected at location WB-31 and the DL exceeded the SQS and CSL criteria.

South Storage Area

All detected chemicals of concern in surface sediments in the South Storage Area and near the Woodard trestle were below the SQS criteria, with the exception of phenol measured in the field duplicate sample at WB-03 using USEPA method 8270 (Table 6; Appendix C). Phenol was detected at 530 µg/kg DW, above the SQS criterion of 420 µg/kg DW. However, the primary sample collected at station WB-03 had a phenol concentration of 53 µg/kg DW. In addition, the phenol concentration measured in the duplicate sample using USEPA method 8270SIM was 26 µg/kg DW. The highest total LPAH and HPAH concentrations were measured at location WB-42 near the Woodard Bay trestle, but concentrations were well below the SQS criteria (Figures 25 and 26). The compound 1,2,4-trichlorobenzene was undetected at location WB-43 (1.5 U mg/kg TOC), but the DL exceeded the SQS criterion of 0.81 mg/kg TOC.

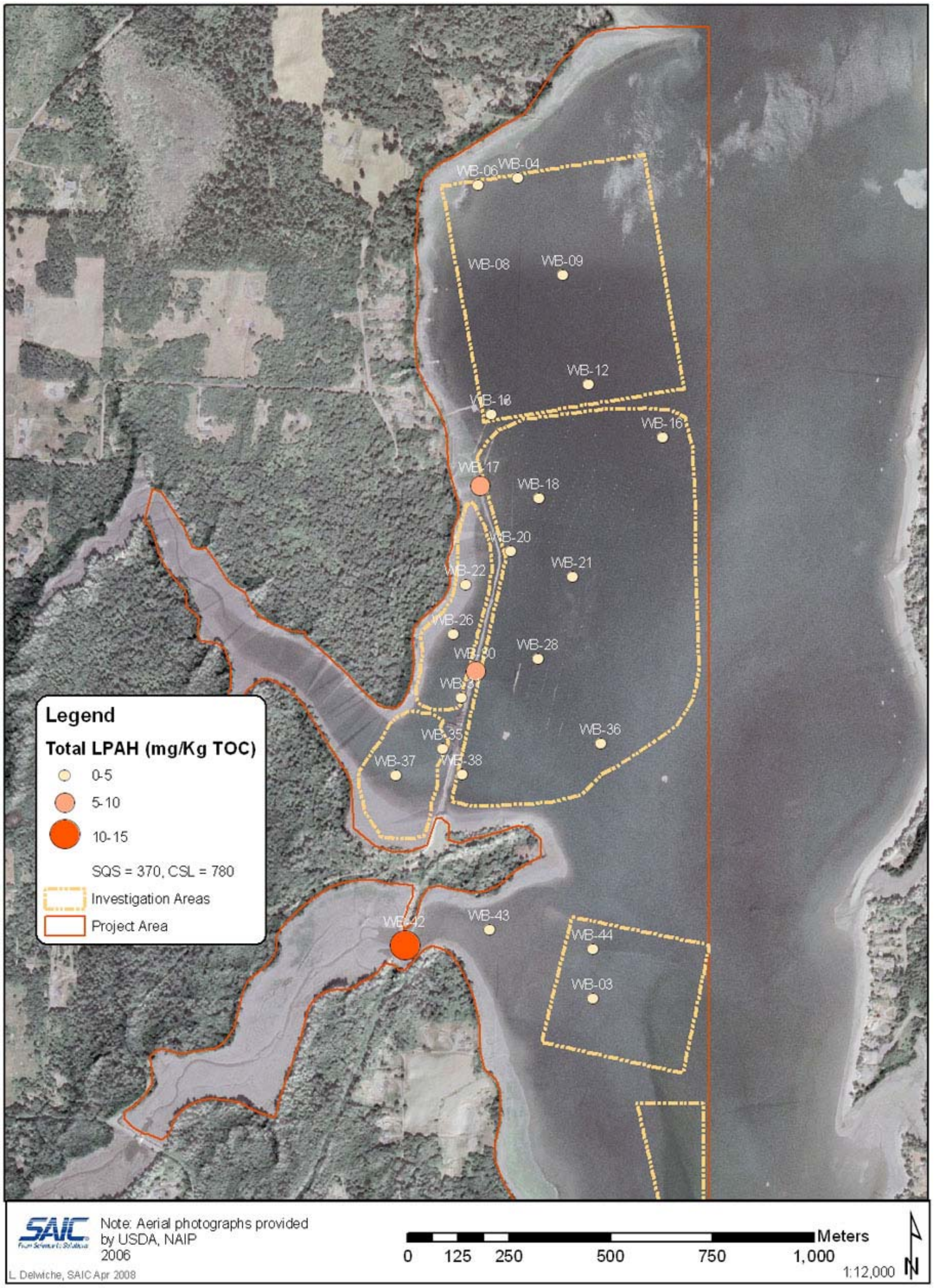


Figure 25. Distribution of Total LPAHs in Surface Sediments

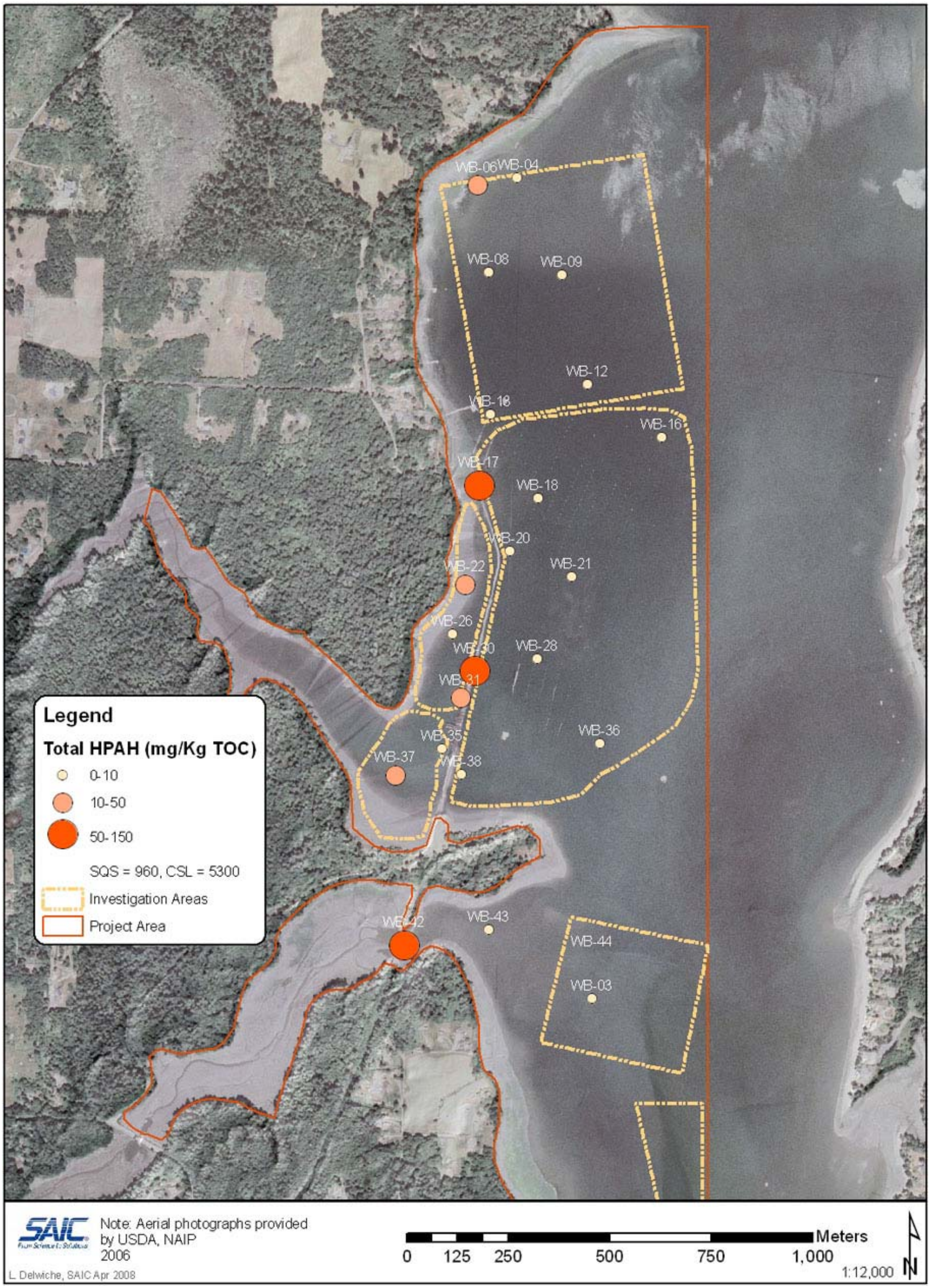


Figure 26. Distribution of Total HPAHs in Surface Sediments

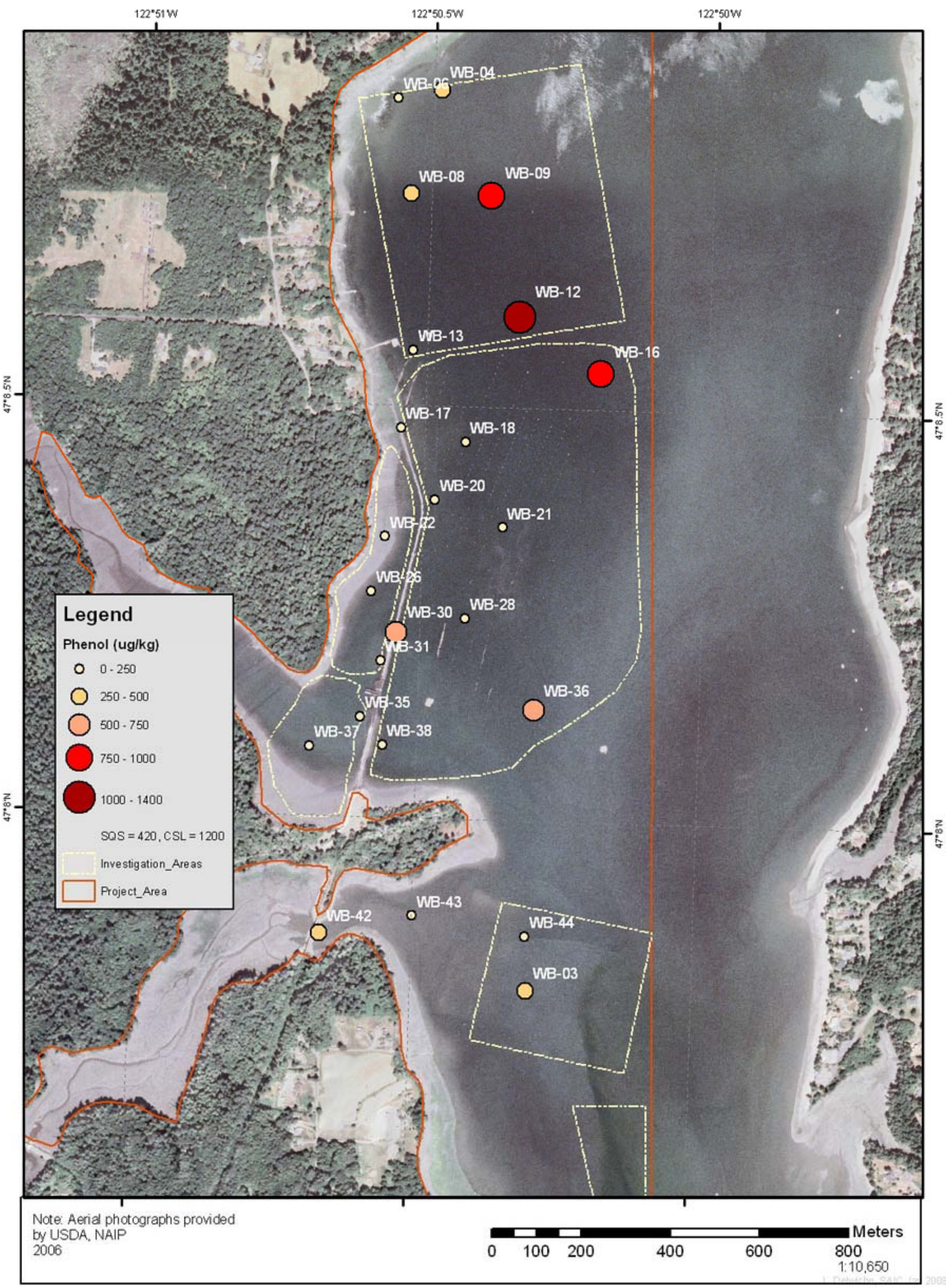


Figure 27. Distribution of Phenol in Surface Sediments using USEPA Method 8270SIM

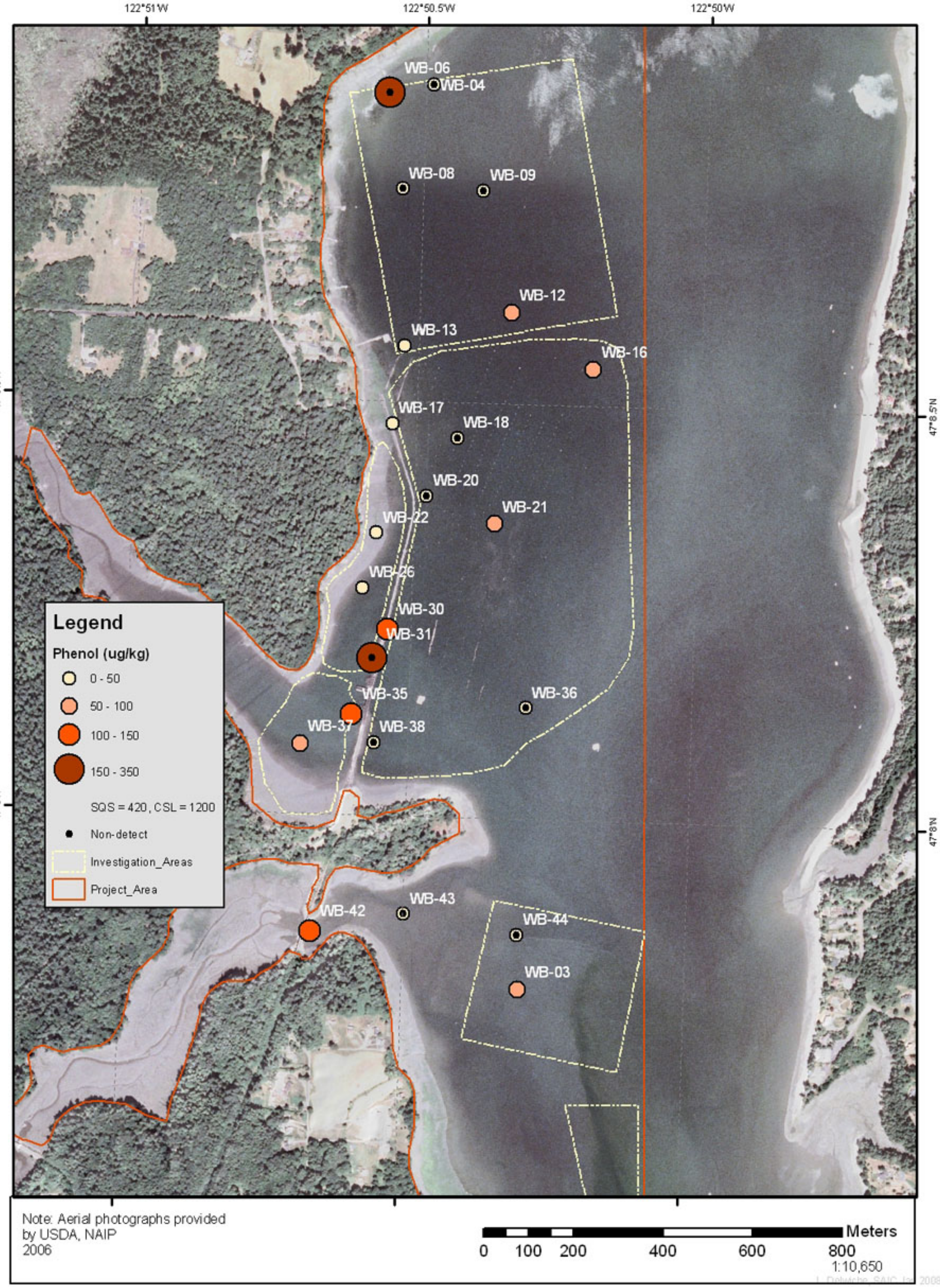


Figure 28. Distribution of Phenol in Surface Sediments using USEPA Method 8270

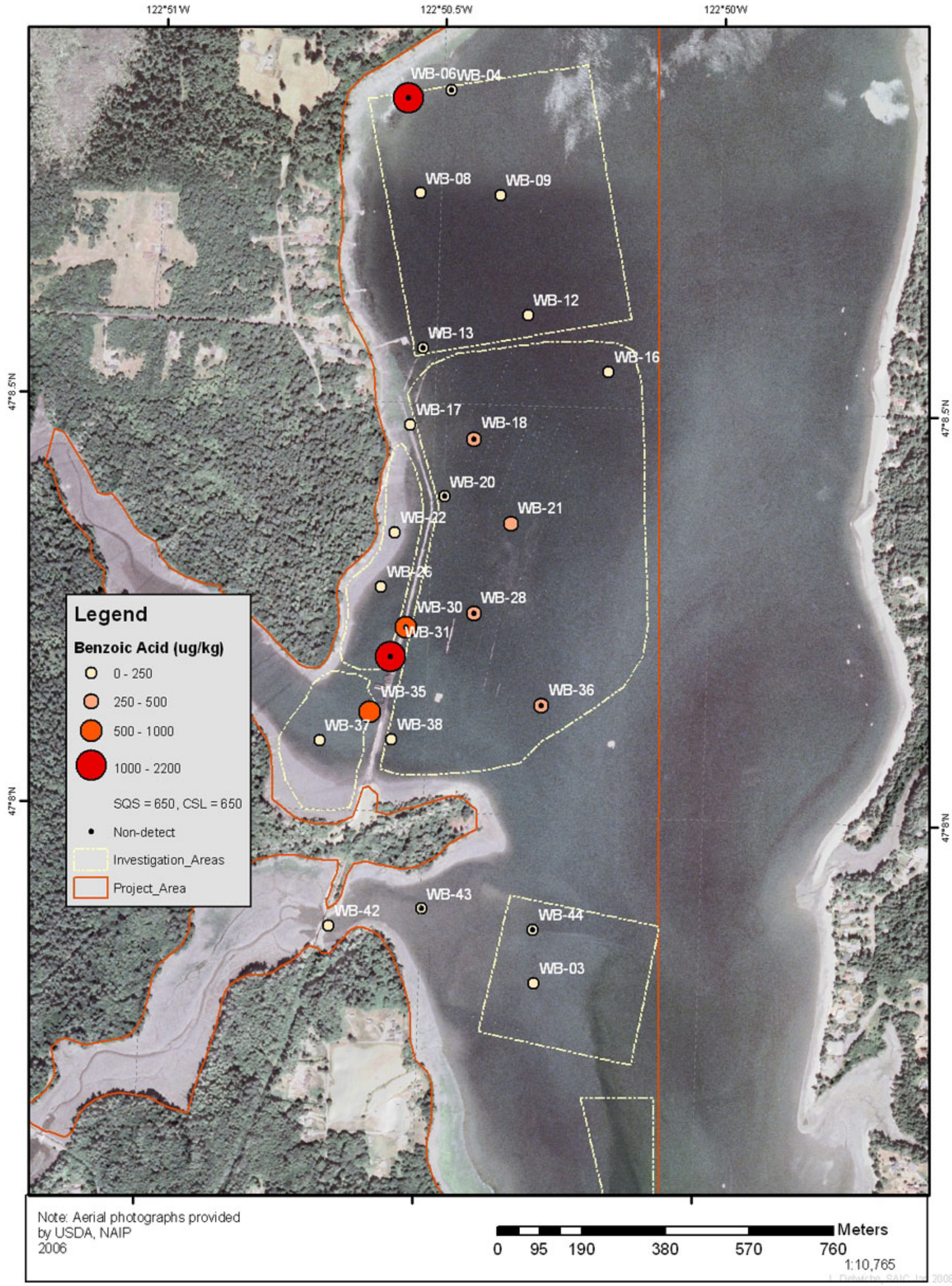


Figure 29. Distribution of Benzoic Acid in Surface Sediments

5.5 Subsurface Sediment Chemistry

Subsurface sediment samples (1 to 3 feet) were collected and analyzed from eight sediment cores in order to identify historical changes in sediment deposition and assess the vertical extent of chemical contamination within the Project Area. Sediment cores were generally collected in close proximity to creosote-treated pilings or in areas where woody debris was expected (Figure 5).

5.5.1 Sediment Conventional Parameters

A comparison of surface (0 to 1 foot) and subsurface (1 to 3 feet) sediment conventional parameters can be found in Table 7. For all locations, significant changes in the grain size distribution did not exist between the surface and subsurface samples. Surface sediment TOC values at locations WB-13, WB-20, and WB-44 were 50 percent higher than the subsurface values. Conversely, at location WB-18 the surface TOC value was 50 percent less than the subsurface. High TVS values were generally found in areas where woody debris was identified using the video probe and collection of sediment cores. In these areas, TVS values increased with the depth with the exception of WB-31 in the Chapman Bay Log Storage Area, where TVS decreased slightly. The highest ammonia concentrations were generally correlated with high TVS values. Ammonia concentrations increased slightly with depth, with the exception of WB-13 in the North Storage Area, WB-18 in the Main Operational Area, and WB-44 in the South Storage Area. Conversely, total sulfides decreased with depth, with the exception of locations WB-08 in the North Storage Area and WB-18 in the Main Operational Area (Table 7).

Table 7. Surface and Subsurface Sediment Conventional Parameter Comparison

Location	Depth (ft)	Total Solids (%)	TVS (%)	TOC (%)	Ammonia (mg-N/kg)	Sulfides (mg/kg)
WB-04-C	0-1	61.9	4.21	1.61	13.2	136
WB-04-C	1-3	73.7	3.17	1.28	25.2	23
WB-08-C	0-1	37.5	18.1	6	47.4	365
WB-08-C	1-3	40.5	23.1	7.05	62	435
WB-13-C	0-1	61.7	5.32	1.55	5.7	88.6
WB-13-C	1-3	78.5	2.7	0.84	2.5	1.01
WB-18-C	0-1	33.3	18.1	8.04	43.6	699
WB-18-C	1-3	33.6	28.9	16.8	40.5	729
WB-20-C	0-1	54.1	10.7	5.06	8.2	203
WB-20-C	1-3	72	3.59	0.37	9.5	16
WB-31-C	0-1	34	33.5	14.4	33.5	463
WB-31-C	1-3	37	29.8	13.9	45.6	402
WB-38-C	0-1	45.4	28.1	12.1	41.6	103
WB-38-C	1-3	37.3	43.5	20.5	47.1	75.3
WB-44-C	0-1	58.2	8.19	6.42	11.6	254
WB-44-C	1-3	76.6	3.56	2.2	6.7	11.4

5.5.2 SMS Chemistry

All detected chemicals of concern in subsurface sediments were below the SQS criteria in the Project Area. The total LPAH concentrations were higher in surface sediments at stations WB-13, WB-18, and WB-44, and higher in subsurface sediments for stations WB-08 and WB-20. Concentrations were similar with depth at locations WB-04, WB-31, and WB-38 (Figure 30). At all locations, the concentration of total HPAHs are greater in surface than subsurface sediments (Figure 31). Phenol concentrations (USEPA Method 8270SIM) were greater in surface than subsurface sediments, with the exception of stations WB-31 (Chapman Bay Log Storage Area) and WB-38 (Main Operational Area), where surface and subsurface concentrations were similar (Figure 32). Phenol concentrations using USEPA Method 8270 were generally similar in surface and subsurface sediment, with the exception of stations WB-13 (Chapman Bay Log Storage Area) and WB-38 (Marine Operational Area), where subsurface concentrations were higher (Figure 33).

Similar to the surface sediment analyses, 2,4-dimethylphenol was undetected in subsurface sediments but the DLs exceeded the SQS or CSL criteria at station WB-18 (Table 8). At WB-13 (North Storage Area), 1,2,4-trichlorobenzene was undetected (1.2 U mg/kg TOC), but the DL exceeded the SQS criterion (0.81 mg/kg TOC). At WB-20 (Main Operational Area), 1,2-dichlorobenenze and 1,2,4-trichlorobenzene were also undetected but the DLs exceeded the associated SQS criteria. Surface samples at stations WB-13 and WB-20 did not exceed SQS criteria for these compounds. Both benzyl alcohol and benzoic acid were undetected at stations WB-31 and WB-38, but DLs exceeded the SQS and CSL criteria. The surface sediment sample at WB-31 also had elevated DLs for benzyl alcohol and benzoic acid that exceeded SQS and CSL criteria. The surface sample at WB-38 did not exceed SQS criteria for these compounds.

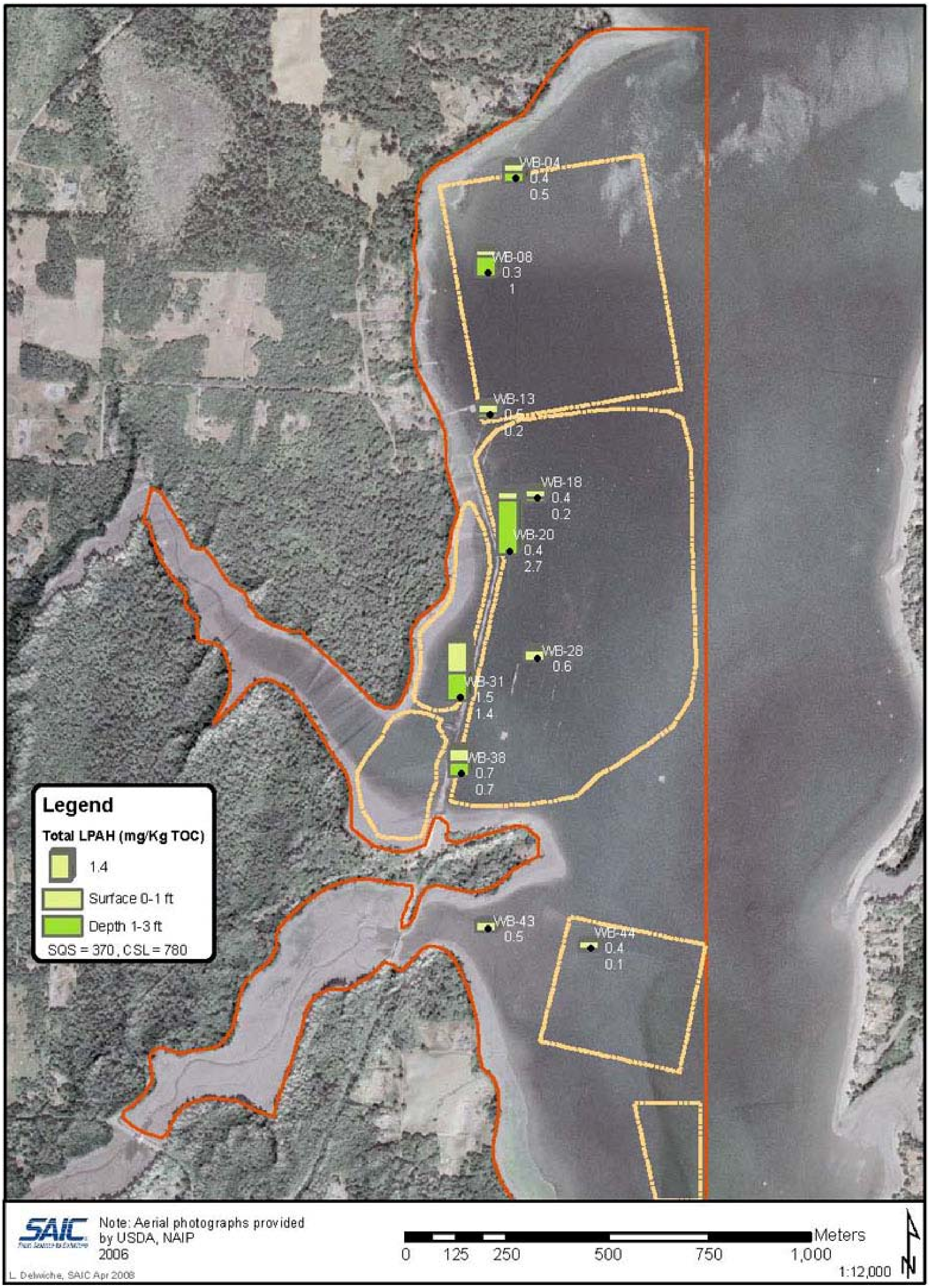


Figure 30. Surface and Subsurface Distribution of LPAHs

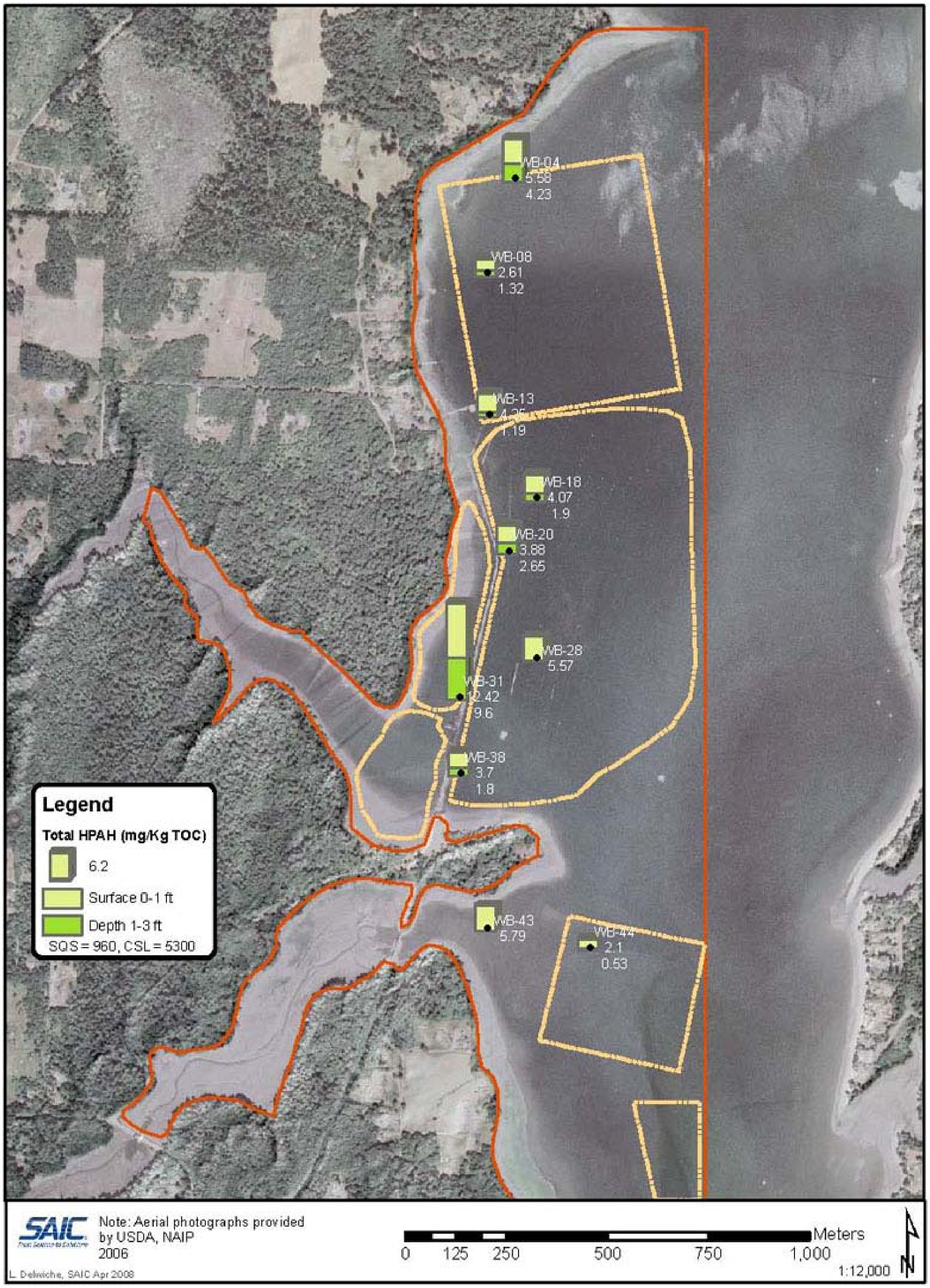


Figure 31. Surface and Subsurface Distribution of HPAHs

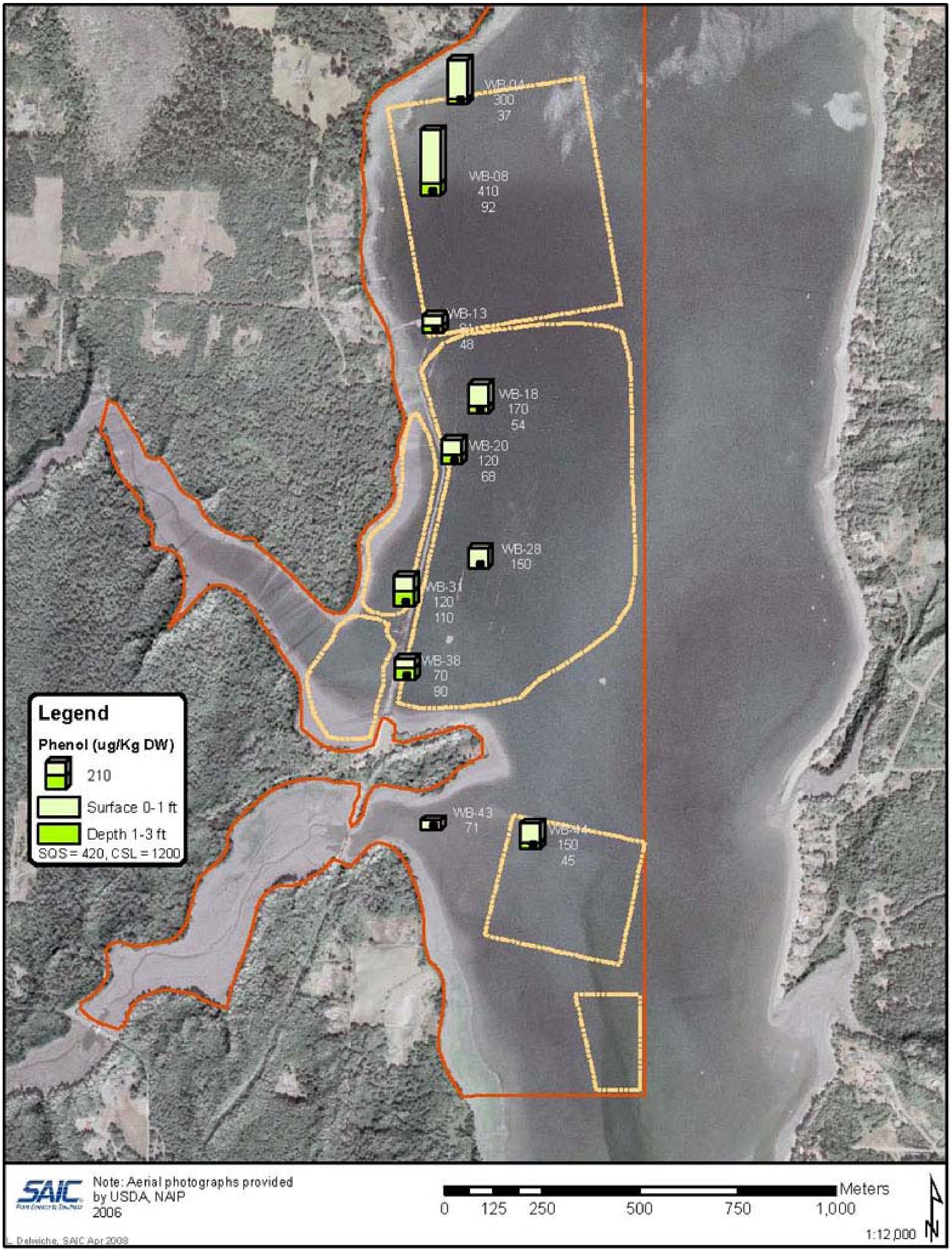


Figure 32. Surface and Subsurface Distribution of Phenol using USEPA Method 8270SIM

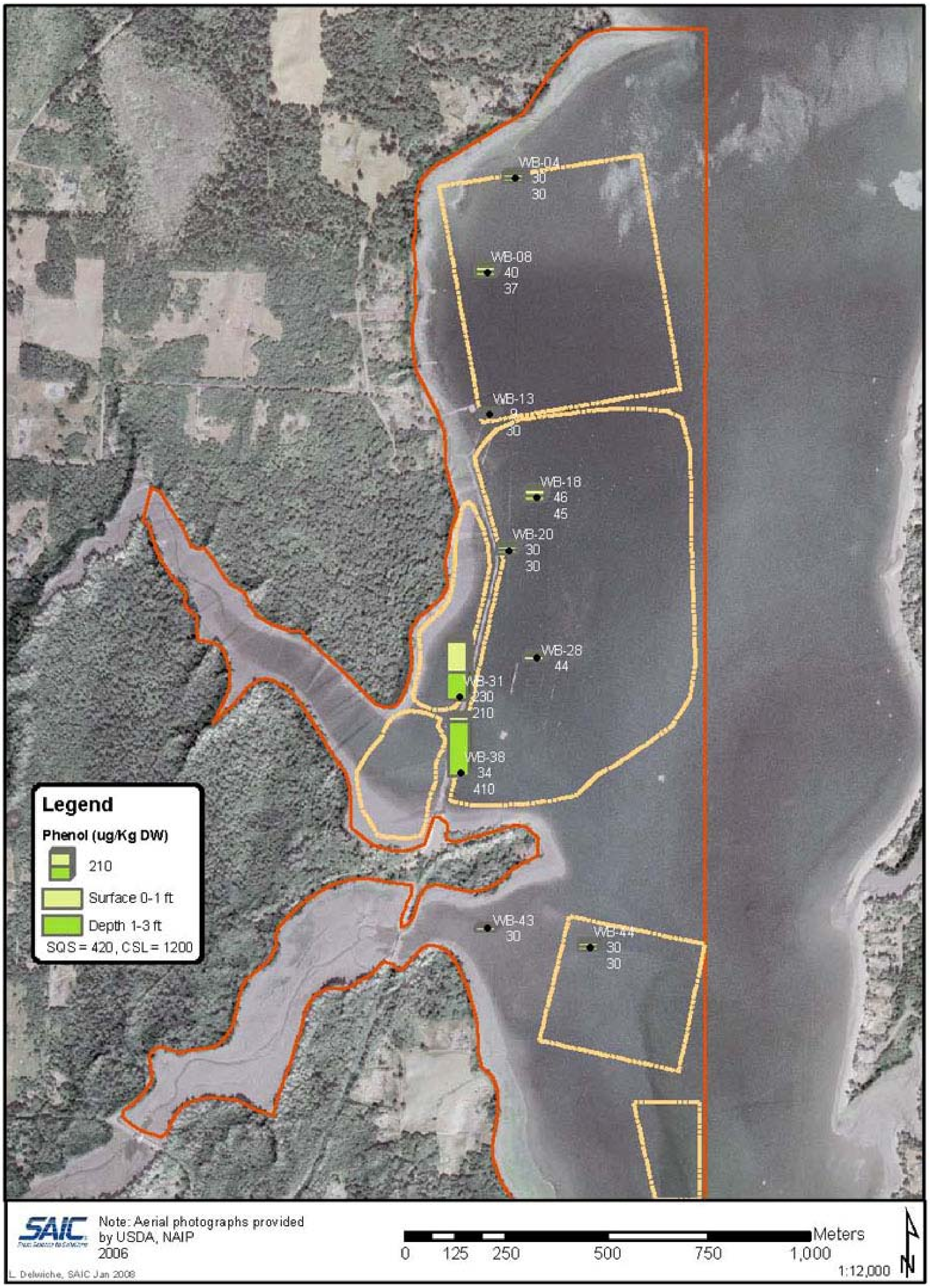


Figure 33. Surface and Subsurface Distribution of Phenol using USEPA Method 8270

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6.0 Discussion

This section provides a discussion of the possible wood-derived chemicals and conventional parameters in the Project Area and a discussion of the elevated DLs reported by the analytical laboratory for some of the SMS chemicals of concern.

6.1 Possible Wood-derived Chemicals

Possible wood-derived chemicals that can lead to sediment toxicity include organic compounds such as phenols, methylated phenols, benzoic acid, and benzyl alcohol. Degradation of wood debris can also lead to elevated levels of conventional parameters such as TOC, TVS, total sulfides, and ammonia. High concentrations of total sulfides and ammonia can also lead to sediment toxicity.

6.1.1 Organic Chemicals

Phenols, methylated phenols, benzoic acid, and benzyl alcohol have previously been identified as biologically toxic compounds liberated by the leaching and degradation of wood debris (Benedict 1971; Pease 1974; Buchanan et al. 1976; Peters et al. 1976; Schermer and Phipps 1976; Lewin and Goldstein 1991). Detected concentrations of phenol in the Project Area were below the SQS or CSL criteria, with the exception of five samples in the North Storage Area (WB-09 and WB-12) and Main Operational Area (WB-16, WB-30, and WB-36) (using USEPA method 8270SIM) and the duplicate sample at station WB-03 in the South Storage Area (using USEPA method 8270). As described in Section 4.7, phenol and methylated phenols were reanalyzed using USEPA method 8270SIM to achieve better DLs than those that were reported using USEPA method 8270. The reanalysis reported higher concentrations of phenol for some samples. In the case of the five samples that exceeded the SQS or CSL criteria, the original phenol concentrations reported using USEPA method 8270 were below the SQS criteria.

The reason for the variability in phenol concentrations between USEPA methods 8270 and 8270SIM is unclear. The laboratory reported that it is not uncommon to see a difference of 30 to 40 percent between two analyses of the same sample due to sample heterogeneity. Phenols tend to associate with oils and tars and may not be distributed evenly in the sediment. USEPA method 8270SIM uses a smaller amount of sample for extraction than USEPA method 8270. Phenols also tend to extract poorly using both methods, and some of the chemical can be lost during extraction (Jacky 2008, personal communication).

Elevated concentrations of phenol were generally found at locations in close proximity to the Chapman Bay Pier and sites of wood debris accumulation (Figure 27). Similarly, 2-methylphenol, 4-methyl phenol, benzoic acid, and benzyl alcohol were found at their highest concentrations at these locations, but detected concentrations did not exceed SQS criteria.

It should be noted that elevated concentrations of these compounds are not uncommon in many areas of Puget Sound. A joint study between Ecology and the National Oceanic and Atmospheric Administration (NOAA) conducted between 1997 and 1999 found three organic compounds (benzoic acid, phenol, and 4-methylphenol) elevated in sediments in many areas of Puget Sound, but with no apparent gradient or pattern (Long et al. 2003). Phenol concentrations exceeded the SQS criteria in 45 of 305 samples (15 percent) and exceeded the CSL criteria in 22 of 305 samples (7 percent). Most of these elevated concentrations occurred in northern Puget Sound (from the U.S./Canada border to Possession Sound). In southern Puget

Sound, elevated phenol exceeding the SQS was observed in the Hylebos Waterway, Henderson Inlet, and the Port of Olympia (Long et al. 2003).

6.1.2 Conventional Parameters

TOC, TVS, total sulfides, and ammonia are conventional parameters that can be elevated in sediments due to the degradation of wood debris. In particular, TVS provides a measure of the organic fraction of the sediment, which is likely correlated to the amount of woody debris in the sediment (Kendall and Michelsen 1997). The SMS does not specify standards for sediment conventional parameters. However, the Dredged Material Management Program (DMMP) specifies that dredged material containing an organic fraction greater than 25 percent dry weight requires biological testing to assess the suitability of the material for open water disposal (Kendall and Michelsen 1997).

Although high concentrations of woody debris were not observed in surface sediments based on SPI and plan-view photography, percent TVS in surface sediments was generally elevated in areas where subsurface woody debris was identified through video probing or sediment core collection. Locations with TVS greater than 25 percent included stations WB-28, WB-31, and WB-38 (Main Operational Area near Chapman Pier). Percent TVS also increased slightly with depth in areas where subsurface woody debris was present (Table 7). TVS in subsurface sediments at stations WB-31 and WB-38 were also greater than 25 percent.

Total sulfides and ammonia are potential sources for sediment toxicity, but the SMS does not specify standards for these conventional parameters. A recent study by Ecology evaluated the toxicity of elevated concentrations of total sulfide and ammonia in Bellingham Bay sediments near the Post Point wastewater treatment plant outfalls (Ecology 2006). Total sulfides were very high, with a range of 862 to 2,620 mg/kg and a mean of 1,637 mg/kg. Ammonia ranged from 15.8 to 56.8 mg-N/kg, with a mean of 29.6 mg-N/kg. Bioassay exceedances of SMS regulatory criteria for this study did not show a strong relationship to the sulfide or ammonia concentrations. However, toxicity was observed at total sulfides concentrations ranging from 1,570 to 2,620 mg/kg, which are much higher than concentrations measured in sediments in the Woodard Bay Project Area (Table 9).

6.2 Elevated Detection Limits

The analytical laboratory (CAS) followed approved analytical procedures and methods for analyzing the SMS chemicals of concern in marine sediments (Ecology 2003). However, elevated DLs can occur during SVOC analysis (USEPA method 8270) due to matrix interferences. For this study, elevated DLs were initially reported for hexachlorobenzene, 1,2-dichlorobenzene, 1,2,4-trichlorobenzene, phenol, 2-methylphenol, 2,4-dimethylphenol, benzyl alcohol, and benzoic acid. In most instances, the reported DLs were above the SQS or CSL criteria. Similar DL problems have been reported in other recent sediment studies in Puget Sound (e.g., Budd Inlet Sediment Characterization; SAIC 2008c).

To address this problem, the analytical laboratory conducted additional analyses that utilized detector systems that were more sensitive to the specific target compounds. Hexachlorobenzene was reanalyzed using USEPA method 8081, chlorinated phenols were reanalyzed using USEPA method 8151M, and phenol and methylated phenols were reanalyzed using USEPA method 8270SIM. The DLs for these additional analyses were below the SQS criteria for several samples. However, additional analyses could not be conducted for benzyl alcohol and benzoic acid to improve the elevated DLs reported using USEPA method 8270. The laboratory for this study did not have an approved SIM method for benzyl alcohol and benzoic acid. The toxicity levels are relatively high for these compounds, and a SIM method is normally not necessary to achieve adequate DLs.

The remaining DLs that exceeded SQS or CSL criteria are summarized in Tables 6 and 8. 1,2-Dichlorobenzene was undetected for all samples, but the reported DLs exceeded SQS or CSL criteria for the surface sample at location WB-22 and the subsurface sample at location WB-20. Similarly, the reported DLs of 1,2,4-trichlorobenzene exceeded SQS or CSL criteria for surface samples at locations WB-06, WB-17, WB-22, and WB-43, and subsurface samples at locations WB-13 and WB-20. 2,4-Dimethylphenol was undetected for all samples but the reported DLs exceeded the SQS or CSL criteria for surface samples at locations WB-08, WB-12, WB-16, WB-18, WB-28, WB-31, and WB-35, and the subsurface sample at location WB-18. The DLs for benzyl alcohol and benzoic acid exceeded the SMS criteria for surface samples at stations WB-06, WB-30, and WB-31 and for the subsurface samples at stations WB-31 and WB-38. However, a review of analytical results from adjacent stations (stations WB-04, WB-28, and WB-35) or surface/subsurface intervals (location WB-38 surface) showed that lower DLs were achieved for these compounds that were below the SQS criteria in nearby areas (Tables 6 and 8). Therefore, the overall distribution of these chemicals in the Project Area does not suggest that the presence of elevated concentrations of these compounds is likely at these stations.

Table 8. Subsurface Sediment Chemistry that Exceed SMS Guideline Values

Station Number	WA SMS	WA SMS	WB-13-C1-3	Q	WB-18-C1-3	Q	WB-20-C1-3	Q	WB-31-C1-3	Q	WB-38-C1-3	Q
	SQS	CSL										
Chlorinated Aromatics in mg/kg TOC												
1,2-Dichlorobenzene	2.3	2.3					2.7	U				
1,2,4-Trichlorobenzene	0.81	1.8	1.2	U			2.7	U				
Ionizable Organic Compounds in µ/kg DW												
2-Methylphenol	63	63										
2,4-Dimethylphenol	29	29			31	U						
Benzyl Alcohol	57	73							140	U	270	U
Benzoic Acid	650	650							1400	U	2700	U

Notes:

DW dry weight

Table 9. Total Sulfide and Ammonia Concentrations in Sediments Measured during the Post Point and Woodard Bay Projects

Study Area	Summary Statistic	# of Samples	Sulfides (mg/kg)	Ammonia (mg-N/kg)
Post Point, Bellingham WA	Min		862	15.8
	Max	11	2620	56.8
	Average		1637	15.8
Woodard Bay Project Area	Min		0.7	2.5
	Max	34	720	62.0
	Average		187	21.7

7.0 Summary and Conclusions

The following summary and conclusions were derived from the Woodard Bay Sediment Characterization study, within the context of the study objectives outlined in Section 2.0.

7.1 Summary

7.1.1 Estimates of the distribution of woody debris in surface sediments

SPI and plan-view images showed minimal wood debris (0 to 8 percent) in surface sediments. Woody debris consisted of small pieces of weathered bark and wood pieces. Fine wood fibers or pulp were not observed. The highest concentrations of woody debris (6 to 8 percent) were observed at stations WB-06 (North Storage Area), WB-17 and WB-18 (Main Operational Area), and WB-08 (South Storage Area). Other recent surveys of areas impacted by wood debris (e.g., Port Angeles, Shelton Harbor) generally found much higher concentrations of wood debris (10 to 40 percent) in surface sediments (SAIC 1999; Ecology 2000).

The SPI and video probe surveys, and surface sediment sampling appeared to identified the presence of approximately 1 foot of ambient sediment deposition over the majority of woody debris deposits (see Appendix B). Based on operations in the Project Area ceasing in 1985, the sediment deposition rate appears to be approximately 1.3 cm/year. This accumulation rate may be comparable to other shallow embayments, but is relatively high compared to an average sediment accumulation rate of approximately 0.1 to 0.7 cm/year in Puget Sound for silty clays and clays (assumed sediment density of 1.7 g/cm^3) (Lavelle et al. 1985). Actual sediment accumulations rates in the Project Area are not known, but could be confirmed using radioisotope analysis methods.

7.1.2 Estimates of the vertical distribution of woody debris

The highest concentration of woody debris (video probe measurements depth-averaged to 6 feet) was measured at the North Storage Area (8.1 percent), followed by the Main Operational Area (7.0 percent) , Chapman Bay Log Storage Area (5.6 percent), and South Storage Area (2.2 percent). Wood debris was generally absent or sparse in the upper 1.0 feet of the sediment column. Abundant logs were not encountered.

On average, the video probe and sediment cores found higher concentrations of wood debris in the upper 3 feet of the sediment column, compared to the 3 to 6 foot interval. However, some stations located near the Chapman Bay Pier appeared to show higher concentrations of wood debris in the 3 to 6 foot interval, compared to the upper 3 feet (e.g., WB-20, WB 30, WB-31, and WB-38).

7.1.3 *The horizontal and vertical extent of chemical contaminants*

All detected SMS chemicals of concern were below the SQS criteria, with the exception of phenol at two locations in the North Storage Area (WB-09 and WB-12) and three locations in the Main Operational Area (WB-16, WB-30, and WB-36) (using USEPA method 8270SIM) and the duplicate sample at station WB-03 in the South Storage Area (using USEPA method 8270).

Slightly elevated concentrations of total LPAHs and HPAHs were measured in surface (0 to 1 foot) and subsurface (1 to 3 feet) sediments near the Chapman Bay Pier and Woodard Bay trestle (creosote-treated piles), but concentrations were well below the SQS criteria.

Following the initial analysis of sediment samples following PSEP guidelines (PSEP 1997a,b,c,d) and SMS Protocols (Ecology 2003), additional analyses were conducted using USEPA methods 8081, 8151M, and 8270SIM to achieve lower DLs for hexachlorobenzene, chlorinated phenols, and phenol/methylated phenols, respectively. Although several compounds and samples achieved lower DLs that were below SQS criteria (e.g., 2-methylphenol, 2,4-dimethylphenol), the DLs for some chemicals still exceeded SQS criteria for some samples (see Tables 6 and 8). In the case of 2,4-dimethylphenol, the DLs were at or slightly exceeded the SQS and CSL criteria.

Possible wood-derived chemicals (phenols, methylated phenols, benzoic acid, benzyl alcohol) were elevated in areas of wood debris accumulation, but detected concentrations were below the SQS and CSL criteria with the exception of phenol at five locations (WB-09, WB-12, WB-16, WB-30, and WB-36). DLs for some of the wood-derived chemicals (benzoic acid and benzyl alcohol) exceeded SMS guidelines for surface samples at WB-06 (North Storage Area), WB-30 (Main Operational Area), and WB-31 (Log Storage Area), and subsurface samples at WB-31 (Log Storage Area) and WB-38 (Main Operational Area). However, the data from adjacent stations suggests that the presence of elevated concentrations of these compounds may not be likely.

Several conventional parameters (TOC, TVS, total sulfides, ammonia) were elevated, likely due to the presence of woody debris. High TVS levels were generally correlated with higher concentrations of woody debris. Locations with TVS greater than 25 percent (exceeding DMMP guideline for initiation of bioassay testing) included stations WB-28, WB-31, and WB-38 (Main Operational Area near Chapman Pier). TVS in subsurface sediments at stations WB-31 and WB-38 were also greater than 25 percent. Total sulfides concentrations ranged from 0.7 to 720 mg/kg, which were lower than the concentrations measured near the Post Point outfalls in Bellingham Bay (862 to 2,620 mg/kg) where sediment toxicity was observed (Ecology 2006).

7.1.4 *Benthic habitat conditions and impacts from confirmed presence of wood debris*

Stage III benthic infaunal (climax community) were present at 56 percent of stations in the Project Area. However, many stations also showed collapsed voids (possible seasonal effect) suggesting a higher percentage of Stage III communities may be present in the latter part of the year. Relict RPD depths are visible at several stations, also suggesting increased biological activity/mixing in the latter part of the year.

Although the abundance and diversity of the benthic community can only be determined through the collection and analysis of benthic infauna samples, the presence of Stage III benthic communities identified through the SPI survey are generally associated with healthy benthic habitat conditions. Conversely, the long-term degradation of the benthic environment frequently involves the loss of Stage III infauna and the dominance of pioneering Stage I infauna (Rhoads and Germano 1986). The Capitellid polychaetes are tolerant to pollution and are a common Stage I organism.

OSI values of +6 or higher (indicative of undisturbed, healthy benthic habitat conditions) were measured at 70 percent of stations sampled in the Project Area. Habitat conditions are likely to improve over time with continued natural sedimentation in the Project Area.

7.2 Conclusions

Wood debris accumulation has resulted in minor impacts (high sediment oxygen demand) to benthic habitat conditions in some areas (North Storage Area – WB-06; Main Operational Area – WB-15, WB-18, WB-24, WB-33, WB-36; South Storage Area – WB-44) due to high TOC input. Input of organic-rich material increase sediment oxygen demand and results in more highly reduced sediments at depth. However, wood debris accumulation in the Project Area has not resulted anaerobic sediment conditions. In other studies of wood debris accumulation in sediments (e.g., Port Angeles and Shelton Harbor), sulfate reducing bacteria mats (e.g., *Beggiatoa* sp.) were observed in areas impacted by wood debris, indicating anaerobic conditions in the sediments (SAIC 1999; Ecology 2000). Mats of sulfate reducing bacteria were not observed at any locations in the Project Area.

The Marine Sampling Systems video probe provided a rapid, low-cost survey method for estimating the vertical distribution of woody debris in sediments. Wood debris measured by the video probe was generally confirmed with the co-located sediment cores. A calculation of confidence intervals between the video probe and core sample data is provided in Appendix E. Additional studies are needed to evaluate and ground-truth the accuracy of the video probe survey methods for measuring wood debris accumulation. In addition, the analysis of TVS at corresponding depth intervals from the co-located sediment cores may provide an additional measure for ground truthing percent wood debris measured using the video probe.

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8.0 EIM Data Entry and Project Database

The chemistry results for this study were entered into Ecology's Environmental Information Management (EIM) system under the study ID WOODARD (http://www.ecy.wa.gov/eim/). In addition, the full study results have been entered into a database format compatible with the Woodard Bay geo-database created by DNR for the Project Area. The database also includes data tables containing the sediment chemistry results for the study. The original geo-database includes the preliminary studies conducted by Hart Crowser (2007a,b,c,d) and was created by Sound GIS. The database will be forwarded to DNR for incorporation into the Woodard Bay geo-database.

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