Jimmycomelately Piling Removal Monitoring Project

Final Report

March 2006

Prepared for:

Jamestown S'Klallam Tribe

1033 Blyn Highway
Sequim, Washington 98382

Prepared by:

PO Box 216, 4729 NE View Dr.
Port Gamble, Washington 98364

210 Taylor Street, Room 15
Port Townsend, Washington 98368

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Acronyms

%RSD	percent relative standard deviation
ASTM	American Society for Testing and Materials
BSAF	biota sediment accumulation factor
COC	chain of custody
DGPS	differential global positioning system
DQO	data quality objective
ELISA	enzyme-linked immunosorbent assay
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
FC	field coordinator
GC/MS	gas chromatography/mass spectrometry
GIS	geographic information system
HHRA	Human health risk assessment
HSP	Health and Safety Plan
JCL	Jimmycomelately Creek
Weston	Weston Solutions, Inc.
MLLW	mean lower low water
PAH	polycyclic aromatic hydrocarbon
PSEP	Puget Sound Estuary Program
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RME	reasonable maximum exposure
RPD	relative percent difference
SDG	sample delivery group
SIM	selective ion mode
SOW	statement of work
TOC	total organic carbon
TBD	to be determined
Tribe	Jamestown S'Klallam Tribe
TSS	total suspended solids
UCL	upper confidence limit

1.0 Introduction

1.2 Problem Definition/Background

The Jamestown S'Klallam Tribe (the Tribe), in conjunction with Clallam County, Washington Department of Fish and Wildlife (WDFW), Clallam Conservation District, Washington State Department of Transportation (WSDOT), US Environmental Protection Agency (USEPA), and local landowners, is in the process of restoring the lower reaches and mouth of Jimmycomelately Creek (JCL) and its estuary in Lower Sequim Bay, Washington (Figure 1.1). As part of this restoration, the creosote-treated pilings located at a historic log storage yard in the intertidal zone at the mouth of the JCL were identified for removal.

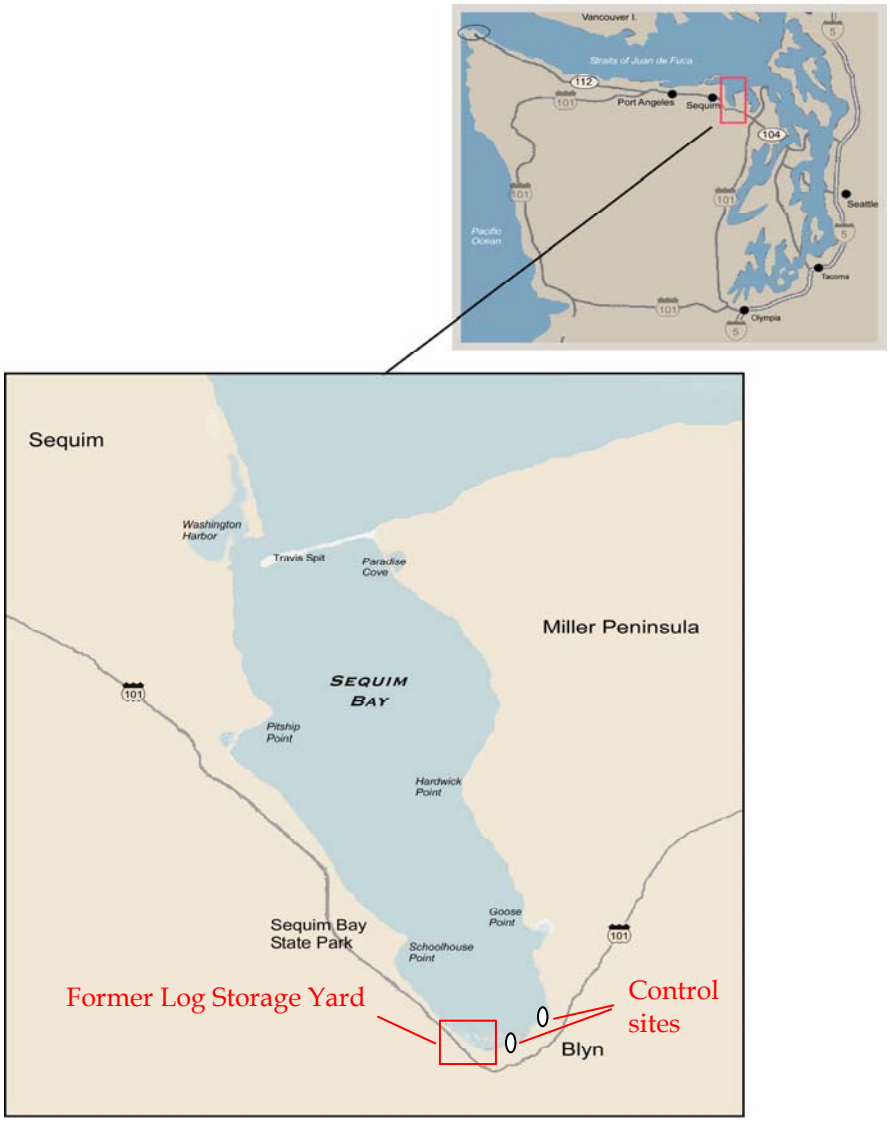


Figure 1.1. Sequim Bay Project Area

The log storage yard in south Sequim Bay operated from 1892 - 2001. Timber logged from the Olympic Peninsula was offloaded into the bay for transport via the Strait of Juan de Fuca and Puget Sound to regional saw mills. In preparation for transport, logs were sorted, rafted, and tied off to creosoted pilings in the log storage yard (Figure 1.2).

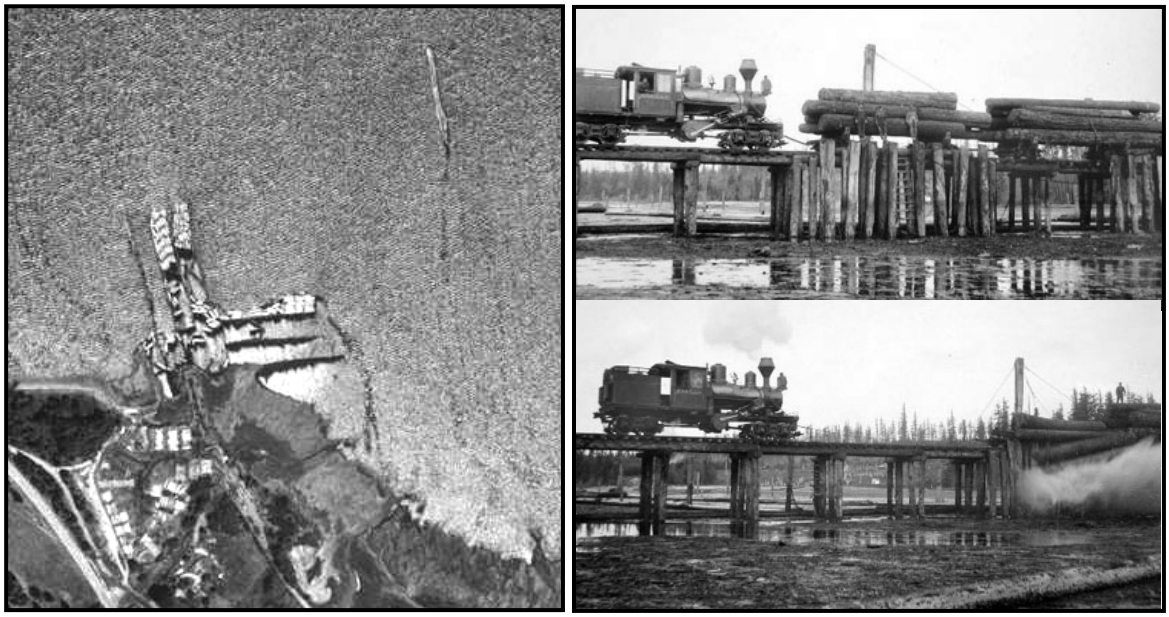


Figure 1.2. Logging activities at the Sequim Lumber Company log storage yard. (historic photo by Bert Herrick, with permission from Tom Robinson).

In the late 1990s, the Jamestown S'Klallam Tribe, WDFW, and WSDOT began to purchase land and acquire easements in the area of the former log yard as part of the larger Jimmycomelately Creek restoration project. The log yard contained 104 pilings, 99 of which were treated with creosote (Figure 1.3).

Creosote is a coal tar distillate that is composed primarily of polycyclic aromatic hydrocarbons (PAHs) with lesser amounts of phenolics and other nitrogen, sulfur, and oxygenated compounds. Creosote has been shown to leach from pilings in the marine and freshwater environment, resulting in elevated concentrations of PAHs in the receiving water column and in sediments as far as 10 m from creosote-piling structures (Poston 2001). Creosote-derived PAHs have been linked with sediment toxicity and elevated tissue concentrations in biota. Creosote also represents a potential human health risk associated with harvest and consumption of PAH-contaminated shellfish.

To our knowledge, there were no data regarding the nature and extent of PAHs in sediment or tissues in the log yard area or in south Sequim Bay. However, it was assumed that the creosoted pilings are a source of creosote-related contaminants in sediments and waters in south Sequim Bay. The pilings at the mouth of

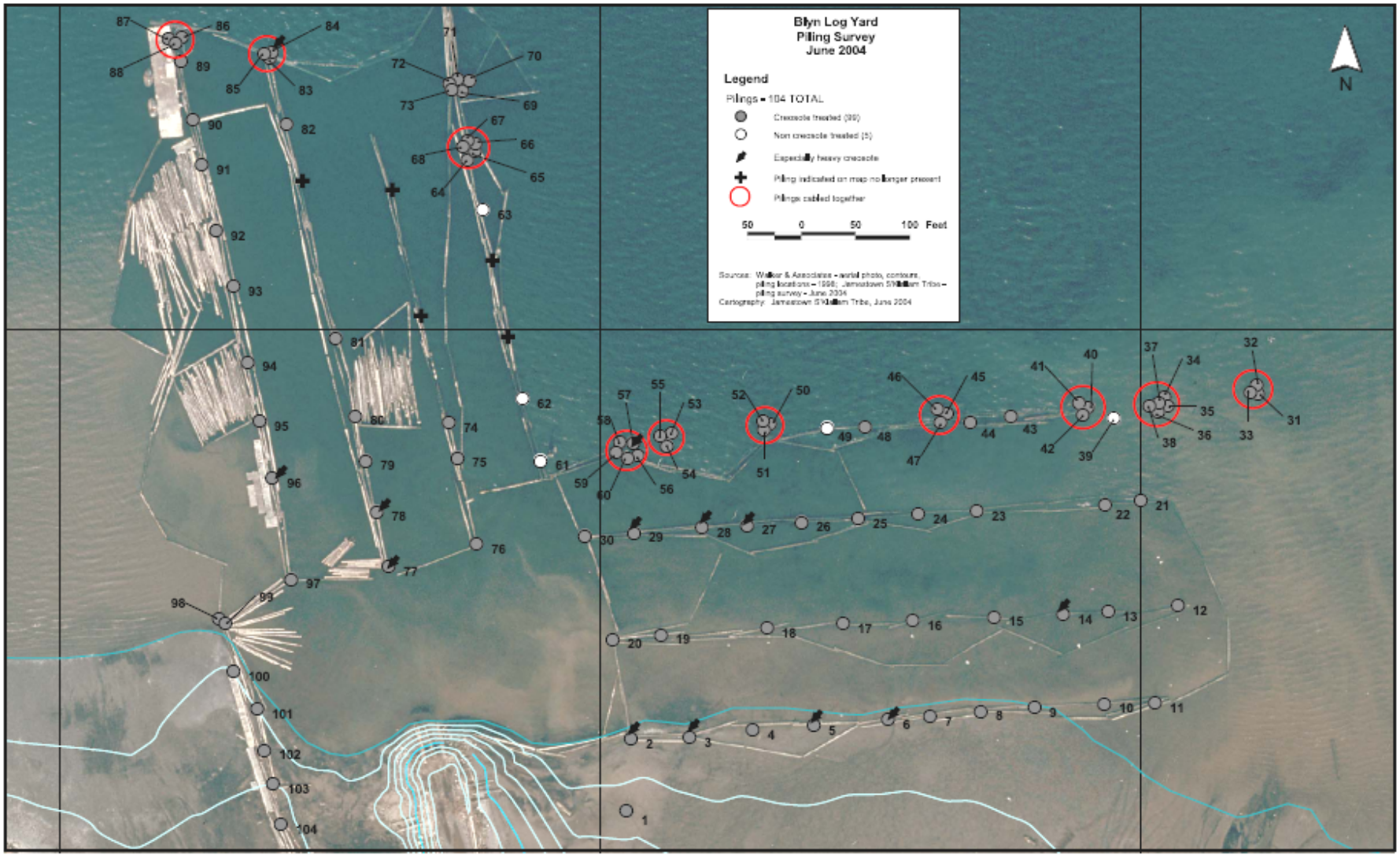


Figure 1.3. Piling locations in south Sequim Bay

Jimmycomelately Creek and their associated "footprint" occupied valuable tidelands that were once rich eelgrass and mudflat habitats that supported shellfish and salmon prey resources. Additionally, the pilings act as perch posts for avian predators of recovering salmon runs entering the Creek.

In order to protect recovering salmon runs, remove a potential source of creosote contamination, and restore the historic habitat and important shellfish beds, the Tribe proposed to remove the 99 creosoted pilings. Both the State of Washington Department of Fish and Wildlife and Department of Natural Resources consider piling removal as the preferred treatment method for creosoted pilings. However, prior to removal, it was recommended that the sediment around the piling be evaluated for PAH contamination.

In a partnership with the EPA Brownfields Program, the Tribe conducted a monitoring program associated with the piling removal. Prior to piling removal, the nature and extent of sediment and tissue creosote contamination were evaluated to assist the Tribe in selecting a piling removal/sediment treatment technology and to evaluate human health risk associated with shellfish harvest and consumption. During piling removal, water-column monitoring was conducted to document suspended sediment and creosote mobilization during removal and to guide post-removal monitoring efforts. Following piling removal, sediment samples were collected in the former log pond to evaluate the nature and extent of PAHs in the former log pond and surrounding areas and to evaluate human-health risk associated with shellfish harvest and consumption in these areas.

The specific objectives of this program were:

Pre-Removal Assessment

- Evaluate the nature and extent of creosote contamination in the vicinity of the pilings prior to piling removal in order to determine the appropriate piling removal methods;
- Evaluate intertidal clam tissue burdens in the vicinity of the creosoted pilings and in two control sites in south Sequim Bay with no creosoted pilings;
- Evaluate the human health risk associated with the harvest and consumption of intertidal clams from the former log yard and from the two control sites;
- Evaluate creosote contamination in surface sediment samples co-located with the log yard tissue samples in order to establish a sediment/tissue relationship that can be used in the risk assessment;
- Based on the sediment evaluations and human health risk assessment, recommend a piling removal technology.

During Removal Monitoring

- Monitor PAHs and total suspended solids (TSS) in the water column during piling removal;
- Determine the areas potentially impacted by sediment mobilized from the log pond.

Post Removal Monitoring

- Evaluate PAH concentrations in the log yard/control sites after piling removal;
- Evaluate the risk to human health associated with intertidal clam consumption following piling removal.

This report presents the results of the assessment and monitoring program. Section 2.0 describes the methods, including the sampling design, field sampling methods, and sample handling procedures, and chemical analyses. Section 3.0 presents the results of this investigation, including sample descriptions and sediment and tissue chemistry results. Section 4.0 presents a summary of the water quality and piling removal monitoring. Section 5.0 presents the post-removal monitoring results. Section 6.0 presents the methods and results of the human health risk assessments. Section 7.0 provides a discussion of the analytical results and implications to human health risk and environmental risk.

2.0 Methods

This assessment and monitoring program included tissue and sediment sampling, chemical analyses for PAHs, water-column monitoring of suspended particulate material and PAHs, data analysis, and human-health risk assessment. This section outlines the sampling strategy and methods that were used during this investigation.

2.1 Pre-Removal Sediment Collection

The purpose of sediment sampling prior to piling removal was to evaluate the distribution of PAHs in sediment in the vicinity of the creosoted pilings. This information was then used to determine which removal technology and control measures were needed for piling removal. In order to evaluate the horizontal and vertical distribution of PAHs in sediment near the creosoted pilings, sediment cores were collected in the vicinity of 12 pilings. Pilings were selected for sampling based on a stratified random sampling design. Strata were location and type of piling. For location, the pilings were split into 6 groups (A, B, C, D, E, and F) based on distance from shore and location in the bay. The purpose of these strata was to capture the potential difference in creosote distribution related to depth (i.e. wave and surge effects, tidal effects) and location (i.e. circulation differences). For types of pilings, the pilings were split into three categories (heavily creosoted pilings, moderately creosoted pilings, and dolphins) based on predicted potential for creosote contamination. The amount of creosote (heavy vs. moderate) was based on visual observations. The location of each sampled piling is presented in Figure 2.1. It should be noted that two stations proposed for sampling (C2 and D7) were not sampled for sediment because they were used for tissue collection and there was a fear of sampling in this previously disturbed sediment.

Three cores were collected from the vicinity of each piling. The location of each sample is based on distance from piling and was designed to support the Tribe's selection of an appropriate piling removal technology. Core samples were collected centered on 2", 6", and 12" from each piling. Samples at each piling were collected along a line away from the piling and were oriented down-current from the piling. Because the pilings were likely inserted into the sediment to a depth of at least 6 to 7 ft., the target depth for the cores was 7 ft. below the sediment surface or to the point of refusal.

2.1.2 Piston Corer sampling

Samples for the 2" and 6" surface cores were collected using a piston-corer deployed off of the Jamestown S'Klallam tribal vessel M/V Whitefeather. Because this type of sampler is manually pushed into the sediment it is capable of sampling very close to structures; however, it is more limited in the depth of samples that can be collected

for certain sediment types (i.e. sand, firm clay). An impact hammer was used to drive the core further into the sediment. Piston cores were able to collect samples to a depth of 1 to 2 feet below the sediment surface before reaching the point of refusal.

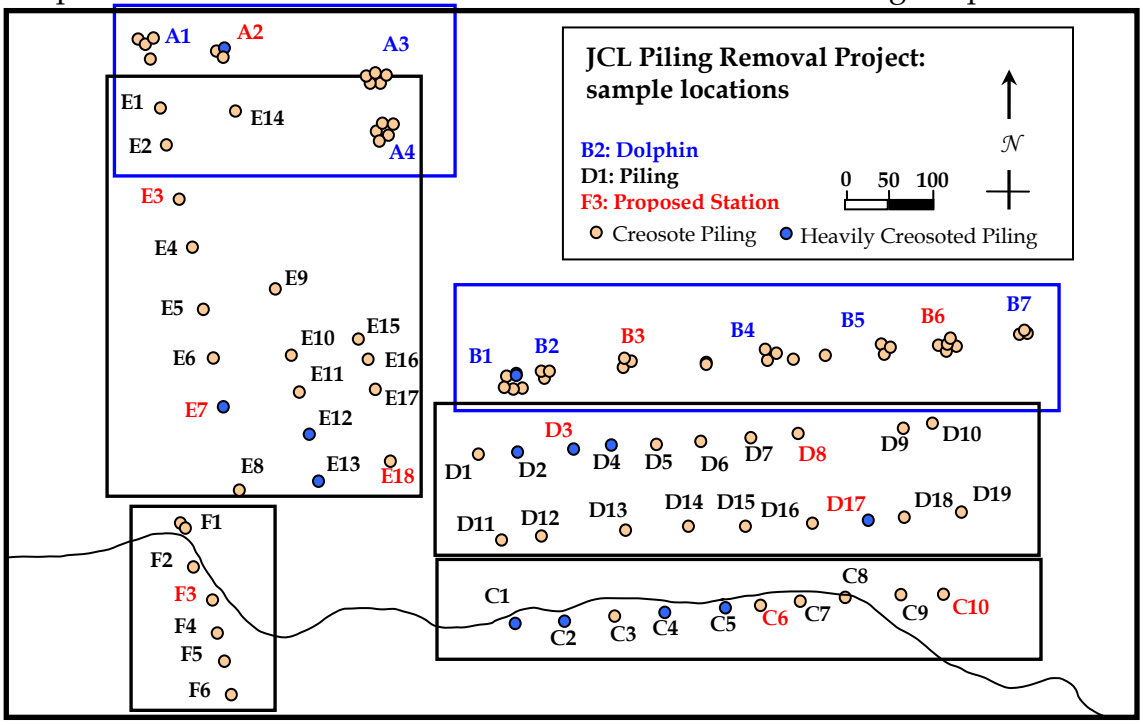


Figure 2.1. Sediment sample locations

The piston corer is an 8-ft. long, 3"-diameter Lexan® tube fitted with a rubber piston. To collect the sediment samples, the vessel was tied to the target piling and the location of the sample located visually. The piston was placed approximately 1 in. from the bottom of the core tube and attached to a fixed point on the stern of the sampling vessel. As the core tube was inserted into the sediment, the piston was held in place, 1 in. above the sediment surface. The top of the core tube was clamped to a steel head fitted with extension rods that allow collecting cores at a variety of water depths. Once the corer had reached the point of refusal, an impact hammer was used to further drive the corer into the sediment. As the corer was inserted into the sediment, the penetration depth was noted on the extension tubes. For each station, the point of refusal ranged from 1 to 3 ft. below the sediment surface. The corer was then extracted by either manually pulling the core, or if needed, pulled up with the hydraulic winch. The core was then stored vertically until any suspended sediment in the water overlying the sediment surface had settled. Following settling, the sediment was extruded from the core tube into a sediment processing tray.

Because the piston corer samples did not reach the target depth of 7 ft., samples were collected using a hand auger and vibracorer to retrieve subsurface samples. The hand auger was used to collect subsurface samples to be collected for the 6"

samples and the vibracorer was used to collect the 12" samples, both surface and subsurface to a penetration depth of 7 to 8 ft.

2.1.3 Hand Auger sampling

For those stations accessible during low tide, a stainless steel hand auger was used to collect the 6" subsurface sample to a depth of 5 – 5.5 ft. below the sediment surface. This was possible for the 6" samples; however, it was not possible to collect samples from the 2" sample with the hand auger, which requires hand-turning the auger with a stainless-steel handle. The hand-auger is a stainless-steel head with a bit to "screw" into the sediment and a bail to collect the sample. The auger head is attached to stainless-steel extension rods fitted with a T-handle that allows the sampler to be screwed into the sediment. Prior to sampling, the auger head was washed with soapy water and rinsed in site water, deionized water and acetone. A shovel was used to removed the surface sediment to a depth of 2 ft. This prevented contamination of the subsurface sediment with surface sediment. The auger was then used to remove sediment between 3 ft. to 5 ft. below the sediment surface. Samples were then removed from the bail and processed in a manner similar to the piston cores.

2.1.4 Vibracorer sampling

The 12" samples were collected using a Rossfelder electric vibracorer (Figure 2.2). The vibracorer uses an enclosed oscillating hammer to vibrate the core head deep into the sediment and is capable of sampling to depth exceeding 40 ft. However, the vibratory hammer is approximately 16" in diameter, preventing this sampler from being deployed closer than 12" from a structure. The vibracorer was deployed on board the research vessel, R/V Kittiwake, owned and operated by Mr. Charlie Eaton. This vessel was fitted with a boom and winch system capable of extracting the fully loaded corer from the bottom. The vibracorer was fitted with a clean aluminum 4"-core barrel and a stainless steel cutter head fitter with "fingers" that would allow sediment to move through the cutter head, but would collapse and close the opening when the core is lifted out of the sediment. Once the corer was lowered to the sediment surface, the vibracorer was turned on and allowed to push into the sediment using the weight of the vibratory head and the vibrations of

Figure 2.2. Electric vibratory hammer in Sequim Bay.

the corer. Once project depth had been reached, the vibratory hammer was turned off and the core pulled from the bottom. Once on the deck of the vessel, the overlying water was poured off and the sediment extruded into a processing tray.

2.1.5 Sample Processing

Immediately prior to processing the cores, overlying water was drained from the core tube, taking care not to lose sediment from the surface of the core. Sediment cores were then extruded from the core tube and placed in a lined core processing tray. The core was then split open with a clean stainless-steel utensil for characterization and sampling. The sediment cores were examined for general physical characteristics and any obvious signs of stratigraphy. Observations included penetration depth, sediment type (i.e. sand, silt, and clay), odor, color, were delineated by an extreme change in sediment composition. Samples were collected using a clean stainless steel spoon, taking care not to collect any sediment that was in direct contact with the processing tray liner. Sediment was placed in a clean stainless-steel bowl, homogenized, and then placed in certified-clean glass jars. Surface and subsurface samples were sampled and processed separately. Samples were held in coolers at approximately 4°C. Once off loaded, samples for PAH and TOC analysis were frozen. Samples for PAH analysis with the enzyme-linked immunosorbent assay (ELISA) were held in the dark, at 4°C prior to analysis.

2.2 Pre-Removal Tissue Sampling and Co-located Sediment

Tissue samples were collected to evaluate the potential for human health risk associated with the future harvest and consumption of intertidal clams from the former log yard. Samples of the clams Japanese littleneck (*Tapes japonica*) and native littleneck (*Prototheca staminea*) clams were collected from locations that represent a presumed concentration gradient in sediments from high PAHs to low PAHs. Locations for tissue samples were limited by the area of exposed intertidal substrate during low tide. Stations used for tissue sampling were those exposed at a -1.5 to -2 ft. mean lower low water (MLLW) tide. Stations represented a group of pilings and were defined by distance from the piling and area within the log yard (Figure 2.3). For example, one "station" included clam tissue within 6" from pilings within the tissue station. A total of 9 clam samples were collected from the log yard; 3 each from within 6" of pilings, within 24" of pilings, and greater than 4 ft. from pilings. Each tissue sample was comprised of approximately 10 clams and no fewer than 6 clams.

Clam tissue was also collected from the two "control" sites within Sequim Bay (Figure 1.1). This provided a reference for evaluating the log yard tissues and allowed for an evaluation of human health risk associated with clams currently harvested by the Tribe. A total of six locations were sampled in each control site. Three (3) samples from each of the control sites were analyzed using GC/MS. The remaining 3 samples were archived for possible future analysis. The decision to

analyze the archived samples will be based on the variability observed in the three samples that were analyzed.

Shallow surface sediment samples were collected and co-located with tissue samples to allow the development of biota-sediment accumulation factors that will be used in the human health risks. Each sample was composited from surface samples collected at each of the clam sampling stations. A total of 9 sediment samples were collected for this purpose. These samples were also used to further characterize the nature and extent of PAH contamination in the log yard.

Clam tissue samples were collected during extreme low tides. Intertidal clams were collected using rakes and shovels. Clams were collected by raking the sediment surface and picking the clams from the sediment and placing them in foil, which was then placed in Whirlpak® bags. Once a sufficient number of clams were collected, clams were placed in coolers at 4°C. Once at the Weston lab, clam shells were rinsed of any sediment or detritus, shucked, and placed whole in pre-labeled, 16 oz. certified-clean glass jars. Samples were then frozen prior to PAH analysis.

Sediment for developing the tissue-sediment relationships was collected concurrent to the tissue sampling. Samples were collected and co-located to the tissue samples. Four ounces of sediment to a depth of 6 cm (the depth of clams sampled) were collected from each tissue sample location and placed into a clean stainless-steel bowl. Once all tissue sample locations were sampled for sediment, the sediment was homogenized using a stainless-steel spoon and a subsample placed into a certified clean glass jar for laboratory analyses. Samples were then frozen prior to analysis. All samples were shipped overnight to the analytical laboratory.

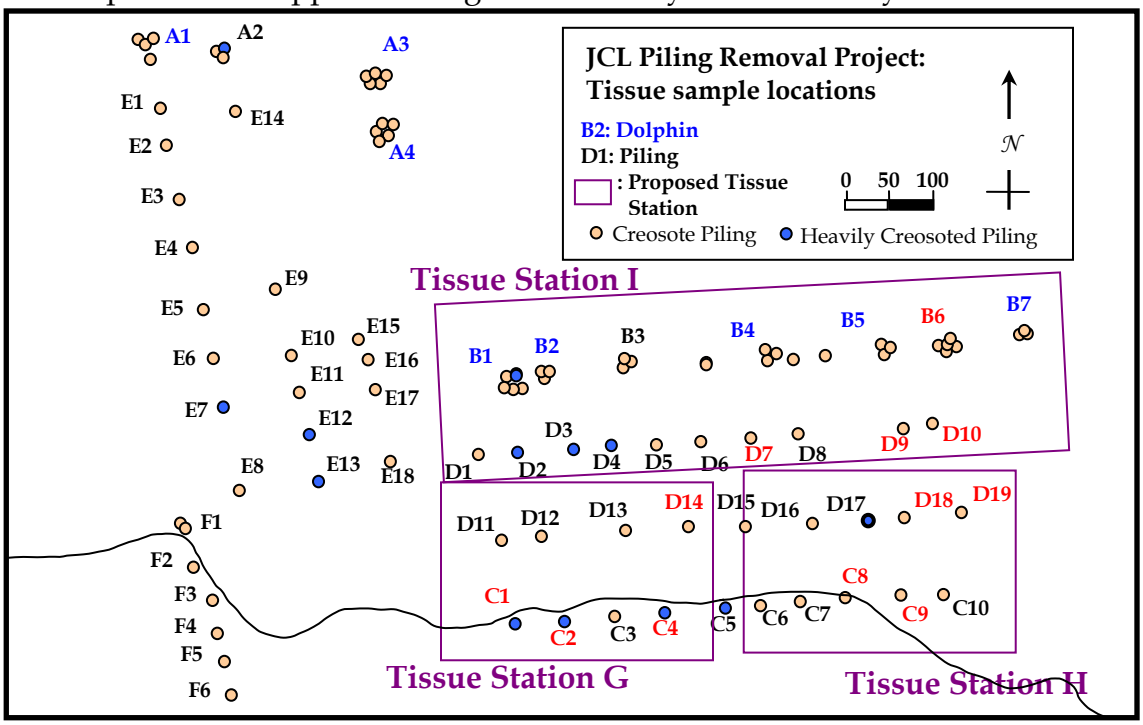


Figure 2.3. Pre-removal tissue sampling areas

2.3 During Removal Water-Quality Monitoring

The nature and extent of PAHs released into the water column during piling removal were evaluated by measuring PAH concentrations in grab samples of seawater from locations near the pilings during removal. To determine whether potentially contaminated sediment was redistributed in Sequim Bay and to determine the extent of sediment resuspension during piling removal, total suspended solids and turbidity were measured before and after piling removal events.

2.3.1 Water Sampling

Water-column grab samples were collected in conjunction with piling removal events. Piling removal events that were monitored were pilings 17, 18, 26, 50-52 ("50 group"), 56-60 ("58 group"), 65, 74, 80, 81, 93, 96, and 97 (using the Tribe's nomenclature; Figure 1.3). Samples were collected within 1 m down-current from the piling from three depths: approximately 50 cm above the sediment surface, 1 to 2 m above the sediment surface, and approximately 1 m below the water surface. Evidence of oil on the water surface was noted, however, there was no sampling of the surface microlayer. Control samples were also collected approximately 1.5 m above the sediment surface from a location upcurrent of the piling(s) being pulled. The location of control samples was as close to the piling as possible; however the influence of the tug boat and barge required that the control samples be collected several hundred feet from the pulling event.

Water-column grab samples were collected at three or four time intervals. Immediately prior to any work on the piling, background samples (T_{-1}) were collected from the control station and each of the test samples. Samples were then collected when the vibratory hammer was activated (T_0), when the piling was pulled from the sediment (T_1), and if possible, approximately five minutes following the pulling event (T_2).

Test samples were collected from a sampling manifold mounted to a mooring buoy that was placed approximately 1 m from the base of the piling. Sampling lines were 50-ft long, Tygon tubing that was attached to the mooring line, with sampling ports placed at each predetermined sampling depth. Once the barge was in place, each of the sampling lines was attached to a peristaltic pump fitted with three channels. Sampling lines were pumped continuously at a rate of 50 ft. per minute. Channels were allowed to run for approximately one minute prior to collecting a sample to ensure that sampling lines were purged and each sample collected was representative of each piling removal event.

A pole bottle sampler was also used to collect grab samples from selected piling removal events. This sampler allowed instantaneous grab samples to be collected from the "plume" from a pulling event. The pole bottle sampler is a bottle mounted

on the end of an extendible pole that can be triggered once at the desired location. This allows the technician to manually collect samples from difficult to reach sample locations.

Control samples for each piling removal event were collected using a van Dorn bottle. The van Dorn bottle sampler is designed to collect a discrete, one-liter water sample once the sampler reaches the desired depth. The sampler is constructed of a lexan tube fitted with two end caps that seal automatically once triggered by a signal weight. Control samples were collected at the same time intervals as the test samples and were collected up-current and upwind of the barge and tug.

Water samples were also collected from the control sites. One control site (C1) was located 150 m east of the former log yard and the second (C2) was located 500 m east of the former log yard. The van Dorn bottle was used to collect the control site samples.

All water samples were collected in pre-labeled, certified-clean, amber glass bottles, which were then placed in a cooler at approximately 4°C. All samples were held in the dark, at 4°C prior to analysis.

3.5.2 Total Suspended Sediment and Turbidity Measurement

Because the creosote-related PAHs in the sediment surrounding the pilings are likely to be strongly bound to the sediment and organic particles, suspended sediment monitoring was used to provide additional information regarding the potential redistribution of PAHs. A combination of optical backscatter sensors (OBS) and a turbidity meter were deployed at locations near the pilings being pulled and from a surface support vessel.

OBS sensors that were used for monitoring were OBS-3A meters manufactured by D&A Instrument Company, Port Townsend, Washington. The OBS sensors measured total suspended solids (TSS) by sending out a beam of light and measuring the amount of that light that was reflected back to the sensor. All parameters measured by the OBS sensors were measured at sampling intervals of 0.5 sec and were stored in a data logger that can be downloaded at the end of the day. OBS sensors were placed on a buoy line at one location within 1 m down-current of the piling that is being removed and one location approximately 5 m down-current of the piling being pulled. Depth to be sampled was approximately 50 cm from the bottom.

A third OBS sensor was deployed alongside a turbidity meter from a sampling vessel. These sensors were used to monitor TSS and turbidity levels at the control stations and to conduct horizontal transects during piling removal. The horizontal transects were conducted to characterize the sediment "plume" that was released during removal. Turbidity was measured using a YSI 6820 multi-parameter water

quality instrument that was fitted with a turbidity sensor. Turbidity is a qualitative term for visible impurity of water that is correlated with total suspended sediment. Qualitative observations regarding the extent of sediment resuspension were also recorded during piling removal.

2.4 Post-Removal Sediment Sampling

Following piling removal, sediment samples and clam tissue samples were collected from randomly determined sample locations throughout the former log pond and neighboring areas. The primary objective of this sampling effort was to determine if creosote-related PAHs were mobilized during piling removal and to determine if the contamination level in the area would represent a human health risk for future shellfish harvest and consumption in the area.

2.4.1 Post-Removal Sediment Sampling

PAH concentrations in the former log yard following piling removal were sampled approximately one month after the completion of piling removal. A total of 50 stations were sampled in the footprint of the former log yard and vicinity. In addition, one sample was collected from each of the two control sites (C1 and C2). The location for the stations in the former log yard and surrounding vicinity were selected based on a random sampling strategy. Several stations were preferentially selected based on observations made during piling removal. Station selection was based on a sampling grid with numbers cells representing an area of 50 ft. by 50 ft. Using a random-number generator in Microsoft Excel, 50 cells were selected for sampling. The selected stations are presented in Figure 2.4.

Sediment to a depth of minimum penetration depth of 5 cm (the depth at which littleneck clams are found) was collected using a modified Ponar grab sampler. The modified Ponar sampler is a stainless-steel, clam shell sampler, with each bucket sampling an area of 0.01 m^2. The mesh covering on the sampler doors allows water to pass through during deployment, reducing the pressure wave that can disturb the flocculent layer on the surface of the sediment.

Prior to sampling, the grab sampler was scrubbed and rinsed with clean seawater. Once on station, the grab sampler was cocked into open position and deployed by hand. The sampler was lowered through the water column. Upon contact with the bottom, the line was allowed to go slightly slack allowing the doors to shut as the grab was lifted off of the bottom. For some stations, the grab was pushed into the bottom to ensure penetration into harder substrate. The sample was then retrieved to the surface and the sediment surface evaluated for acceptability. Sample acceptability was based on the following criteria:

- Minimum penetration depth of 5 cm,
- Minimal visible leakage upon recovery to the sample platform,

- No over-penetration and minimal visible signs of disturbance on sample surface.

The chemistry sample was collected after the overlying water was removed from the grab sampler. The upper 5 cm of the sediment surface was then removed using a stainless-steel spoon, homogenized in a stainless-steel mixing bowl, and then placed in a 500 mL amber glass container for PAH analysis. Samples were held in the dark, at 4°C in a cooler on the vessel. Samples were frozen prior to shipment to the analytical laboratory. The chemistry sample was collected after the overlying water was removed from the grab sampler. The upper 5 cm of the sediment surface was then removed using a stainless-steel spoon, homogenized in a stainless-steel mixing bowl, and then placed in a 500 mL amber glass container for PAH analysis. Samples were held in the dark, at 4°C in a cooler on the vessel. Samples were frozen prior to shipment to the analytical laboratory.

2.4.2 Post-Removal Tissue Sampling

PAH concentrations in clam tissues from the former log yard and neighboring areas following piling removal were sampled on September 17, 2005, approximately 50 days after the completion of piling removal. A total of nine stations were sampled in the footprint of the former log yard and vicinity (Figure 2.5). In addition, three samples were collected from each of the two control sites (C1 and C2). In addition, three samples were collected from three locations near the Tribal Center (TC) on the southeastern portion of Sequim Bay. The TC stations were used to evaluate shellfish in an area which had pilings removed at the same time as those of the former log yard.

Samples of the clams Japanese littleneck (*Tapes japonica*) and native littleneck (*Protothecа staminea*) were collected within the former log yard using a stratified random sampling design (Table 2.1). Stations used for tissue sampling were those exposed at a -1.5 to -2 ft. MLLW tide. Each tissue sample was comprised of approximately 10 clams and no fewer than 6 clams.

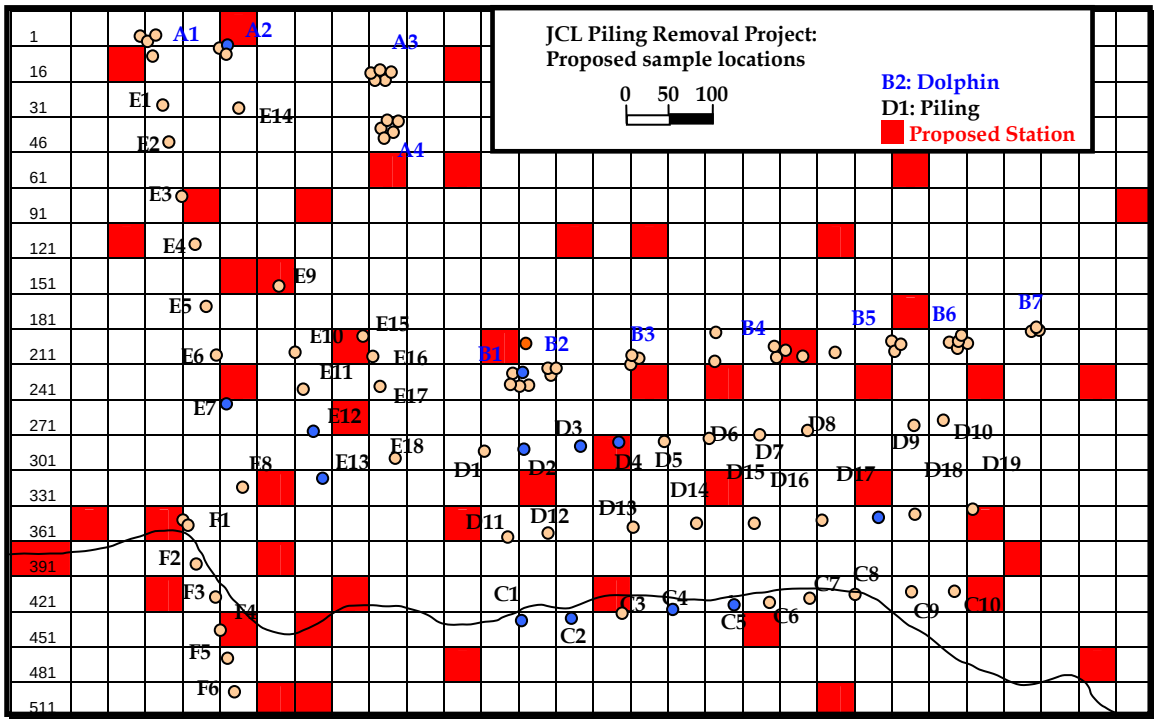


Figure 2.4. Proposed Station Locations for Post-Removal Sediment Sampling

Table 2-1. Sample locations of clams collected for Post-Removal in the former log yard.

Sample Location	Latitude (°N)	Longitude (°W)
PC 1	48° 01.380	123° 00.280
	48° 01.634	123° 00.460
PC-2	48° 01.632	123° 00.492
PC-3	48° 01.629	123° 00.544
PC-4	48° 01.613	123° 00.729
PC-5	48° 01.370	123° 00.320
	48° 01.611	123° 00.539
PC-6	48° 01.615	123° 00.504
PC-7	48° 01.614	123° 00.481
PC-8	48° 04.577	123° 00.505
PC-9	48° 01.581	123° 00.545

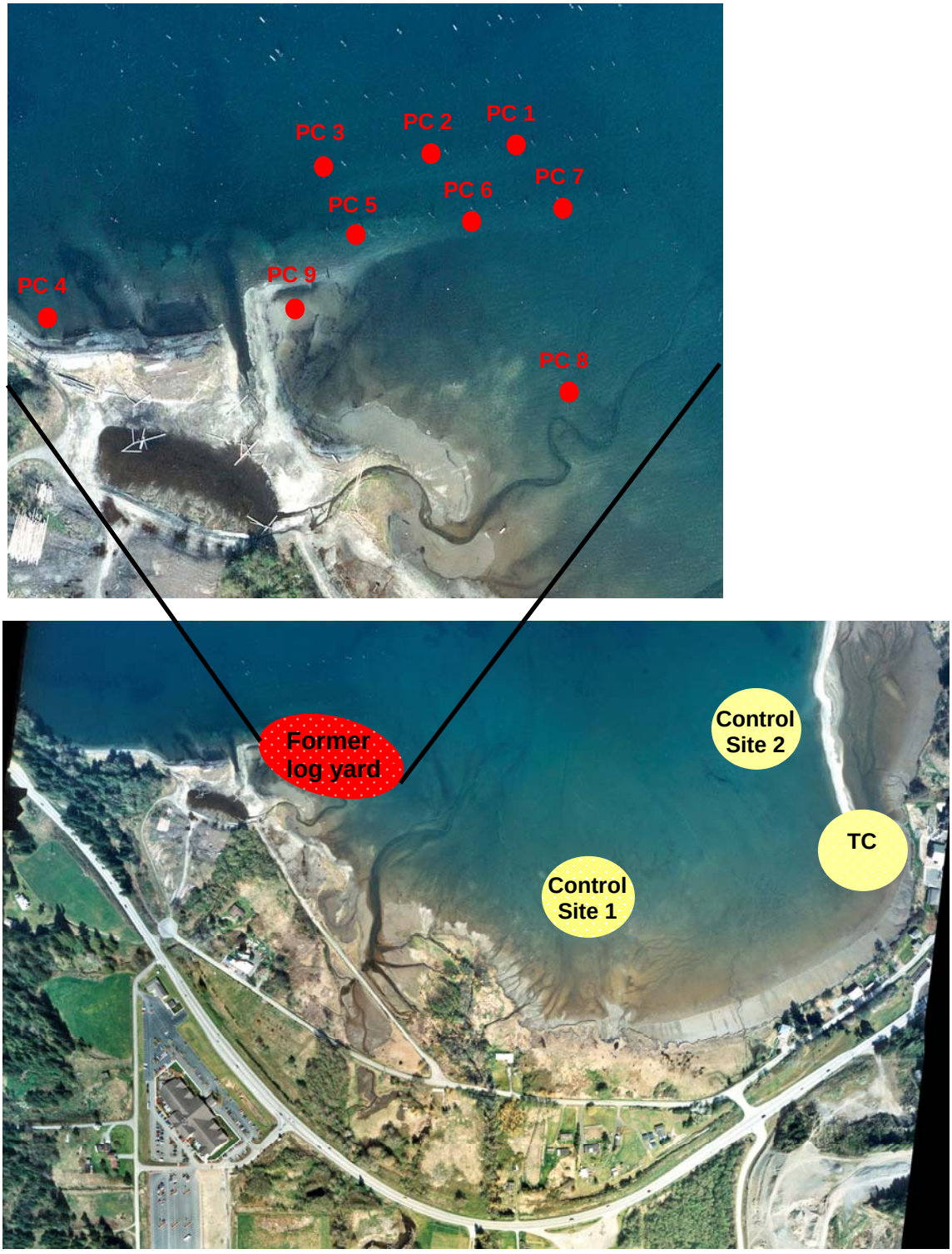


Figure 2.5. Sample locations of clams collected for tissue analysis on 17 September, 2005 in South Sequim Bay.

2.5 Chemical Analysis Methods

Surface and subsurface sediment samples were analyzed for percent solids, total organic carbon (TOC), and PAHs. Tissue samples were analyzed for percent lipids and PAHs. Water samples were analyzed for PAHs. With the exception of ELISA, all analyses were conducted by Analytical Resources Incorporated. The analytical chemistry requirements for the sediment, tissue, and water samples are presented in Table 2.2. ELISA analyses were conducted by Weston at the Port Gamble Environmental laboratory.

The following sections briefly describe the methods used for analysis of sediments, waters, and tissues. Analyses followed established procedures. Quality control samples included method blanks, matrix spikes (MS), matrix spike duplicates (MSD), and matrix duplicates. The reporting limits are the lowest concentration that the method is able to detect. The MS, MSD, and matrix duplicate were used to evaluate analytical precision. The MS, MSD, and blank were used to evaluate analytical accuracy. Precision is a measure of how variable the measurements are when repeated and accuracy is a measure of how close the measurement is to the true value.

Table 2-2 Summary of data quality objectives

Parameter	Units	Method Reporting Limit	Precision	Accuracy	Method	Reference	Sample Holding Time	Notes
Sediment								
Semivolatile Organics	µg/kg dw	20	±30%	10-177%	GC/MS SIM	EPA 8270C-SIM	14 days[a] 1 year	Cool/4°C Frozen
PAH (ELISA)	µg/kg ww	40	±30%	30-160%	ELISA	EPA 4035	14 days[a]	Cool/4°C
TOC	% dw	0.02	±20%	75-125%	Combustion	PSEP 1997b	28 days	Cool/4°C
Moisture content	%t ww	0.1	±20%	Na	Oven-dried	EPA 160.3	7 days	Cool/4°C
Tissue								
Semivolatile organics	µg/kg ww	20	±40%	32-131%	GC/MS-SIM	EPA 8270 SIM	40 days	frozen
Lipid	% dw	0.1	±20%	Na	gravimetric	Bligh-Dyer	6 months	frozen
Water								
Semivolatile Organics	µg/L	2.0	±30%	10-177%	GC/MS SIM	EPA 8270C-SIM	14 days[a] 1 year	Cool/4°C Frozen
PAH (ELISA)	µg/L	1	±30%	30-160%	ELISA	EPA 4035	14 days[a]	Cool/4°C

[a] 14 days until extraction, 40 days to analysis from time of extraction
GC – gas chromatography
MS– mass spectrometry
na- not applicable
PSEP– Puget Sound Estuary Program
SIM– selected ion monitoring

2.5.1 Total Organic Carbon

Total organic carbon is the amount of non-volatile, partially volatile, volatile, and particulate organic carbon compounds in a sample. Methods for TOC analysis followed those of PSEP (1995). Each sediment treatment was dried and ball milled to a fine powder. Before combustion, inorganic carbon in the sample was removed by acidification. The TOC in the sample was then determined by measuring the carbon dioxide released during combustion of the sample and reported as percent of dry weight. Quality control measures included method blanks and one duplicate analysis per batch of no more than 20 samples.

2.6.2 PAHs

Sediment samples were screened for PAHs using ELISA. Samples exceeding the detection limits, were then selected for gas chromatography/mass spectrometry (GC/MS). All sediment samples were analyzed for total organic carbon.

The ELISA method uses antibodies developed to react with PAHs to provide a semi-quantitative analysis of total PAH in sediment (SDI 2004). Briefly, the sample (sediment or water) was extracted in methanol, and then placed in a diluent resulting in a sample dilution of 1:100. Water samples were not extracted by methanol, but were placed in methanol to achieve the appropriate dilution. PAH-reactive antibodies were then added to the PAH-diluent solution and incubated for 30 minutes. This was followed by the addition of magnetic particles that bound to the PAH-antibody complex, and an additional 20-minute incubation. The PAH-antibody-magnetic particles were then removed from solution using a powerful magnet. Any additional antibody was then reacted to a color indicator, followed by spectral analysis on a spectrofluorometer. Samples with lower PAH concentrations were darker in color and lower in transmissivity than samples with higher concentrations.

Selected water and sediment samples and all tissues were submitted for quantitative PAH analysis with GC/MS. Analysis for 16 PAHs in the JCL sediment and water treatments followed EPA Method 8270C. These compounds were extracted from the sample matrix using 1:1 acetone/dichloromethane as the extraction solvent. All acetone was evaporated at the end of the extraction process. Tissues extracts were further processed with silica fractionation prior to analysis to remove any additional interference. A portion of the extract was then analyzed by gas chromatography/mass spectroscopy in the Selective Ion Mode.

Quality control measures included one method blank, one matrix duplicate, and one MS/MSD per batch of no more than 20 samples. An MS and MSD solution consisting of phenanthrene, chrysene, and benzo(k)fluoranthene was added to each sample to assess the accuracy and precision of the measurement. Method blanks and matrix duplicates were also run to assess the accuracy of the measurement.

2.5.3 Lipids

Lipids were analyzed in tissues using gravimetric analysis (Bligh and Dyer 1959). Tissue samples were homogenized and extracted in chloroform and methanol. The extract was then filtered and separated in deionized water. Lipid content was determined gravimetrically by measuring triplicate aliquots of the chloroform layer, air-drying the solvent, and weighing.

2.6 Human Health Risk Evaluations

The methods used to evaluate human health risks associated with the sediment and clam tissues collected from the former log yard and controls sites are presented in Section 6 of this report.

2.7 Environmental Risk Evaluation

Risks to environmental receptors were based on comparisons of PAH concentrations in sediment collected in the former log yard to Washington Department of Ecology Sediment Quality Standards (SQS) and Sediment Cleanup Screening Levels (CSL) for the marine waters of Washington (Washington Administrative Code [WAC] Chapter 173-204). The SQS values represent the concentration below which no adverse effects to biological resources in Puget Sound sediment are expected. These values are based on historic invertebrate effects data of sediment in Washington State. The CSL represents that concentration above which adverse effects are considered to be likely. Because the availability and toxicity of PAHs are affected by the organic carbon content of the sediment, the concentrations for this comparison were normalized to organic carbon (OC). Also, it is important to note that these values are expressed in mg/kg, or mg/kg OC.

3.0 Results of Pre-removal Sampling

This section summarizes the results of sediment and tissue analysis prior to piling removal, water sampling during piling removal, and sediment sampling after piling removal.

3.1 Pre-Removal Sediment Sampling

Sediment cores were collected on December 7 through 9, 2004 (for 2″ and 6″ stations) January 6, 2005 (for 12″ stations). Cores were collected from the vicinity of 12 pilings in the log yard. The stations sampled and coordinates for each sample are presented in Table 3.1 and Figure 3.1. Note that the coordinates reported represent the 2″, 6″, and 12″ samples at each piling.

	Coordinates (NAD 1983)		
Station	Latitude	Longitude	Samples Collected
A2	48° 01.7189	123° 00.6492	A2-2S, A2-6S, A2-12S, A2-12SUB
B3	48° 01.6649	123° 00.5340	B3-2S, B3-6S, B3-12S, B3-12SUB
B6	48° 01.6683	123° 00.4461	B6-2S, B6-6S, B6-6SUB, B6-12S, B6-12SUB
C6	48° 01.6190	123° 00.4939	C6-2S, C6-6S, C6-6SUB, C6-12S, C6-12SUB
C10	48° 01.6222	123° 00.4429	C10-2S, C10-6S, C10-6SUB, C10-12S, C10-12SUB
D3	48° 01.6485	123° 00.5481	D3-2S, D3-6S, D3-12S, D3-12SUB
D8	48° 01.6518	123° 00.4851	D8-2S, D8-6S, D8-6SUB, D8-12S, D8-12SUB
D17	48° 01.6355	123° 00.4653	D17-2S, D17-6S, D17-6SUB, D17-12S, D17-12SUB
E3	48° 01.6927	123° 00.6602	E3-2S, E3-6S, E3-12S, E3-12SUB
E7	48° 01.6533	123° 00.6454	E7-2S, E7-6S, E7-12S, E7-12SUB
E18	48° 01.6400	123° 00.6181	E18-2S, E18-6S, E18-12S, E18-12SUB
F3	48° 01.6108	123° 00.6455	F3-2S, F3-6S, F3-6SUB, F3-12S, F3-12SUB

Table 3.1 Sample coordinates for sediment cores collected from the log yard.

S = Surface Sample

Sub = Subsurface Sample

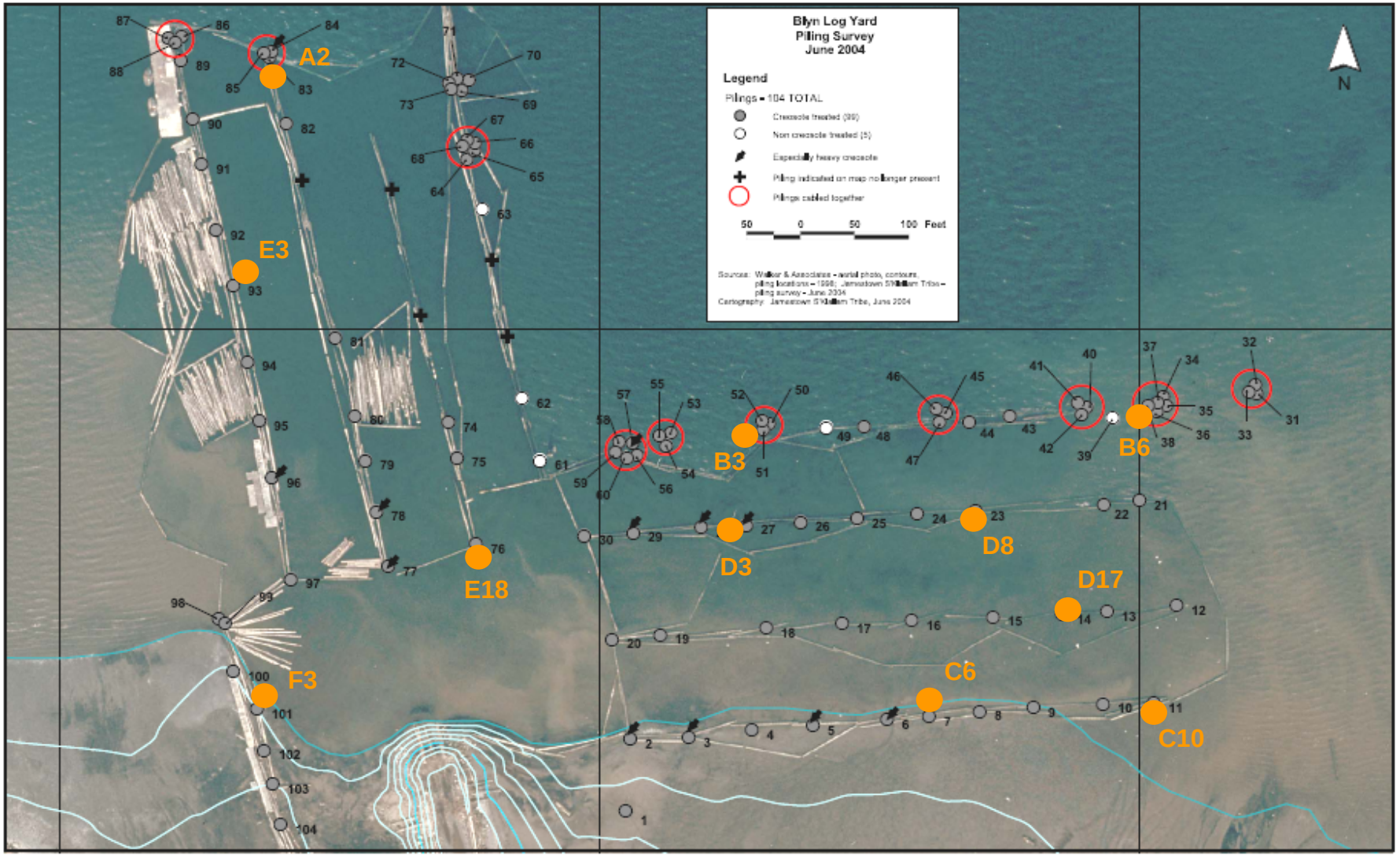


Figure 3.1. Locations of sediment cores.

The core logs with the field observations of sediment collected from the log yard are presented in Appendix C. The penetration depths for the piston cores collected at the 2″ and 6″ stations (cores centered 2″ from the piling and 6″ from the piling) were generally between 1 ft. and 3 ft. below the sediment surface (BSS), at which point, the sampler no longer penetrated the sediment. This penetration depth was consistent across the log yard, indicating a consistent firm layer underlying the surface material.

For stations accessible at low tide (-3.0 MLLW), subsurface samples were retrieved for the 6″ stations using the hand auger. Penetration depth achieved with the hand auger was 5.0 to 6.0 ft BSS. For the 12″ samples collected with the vibracorer, penetration depth was 7.0 ft to 8.5 ft BSS.

A schematic drawing of the sediment characteristics for cores collected from the 12″ stations is presented in Figure 3.2. Although this presentation is based on the 12″ cores, the sediment layers and characteristics are consistent with those of the 2″ and 6″ stations. The surface sediment across the log yard was characterized by a very-fine sand/silt/clay mixture that was olive green to dark brown in color. Surface sediment, to approximately 1.5 to 2 ft. BSS frequently contained woody debris or shell hash. Shell hash was generally limited to the upper 6″ of the core and was a mixture of clam, barnacle, and snail shells. Those samples with shell or wood debris frequently had a sulfur odor. Stations A2, B3, B6, and C10 had evidence of oil sheen in the surface sediment.

The subsurface samples were generally characterized by relatively dry, medium - coarse sand with large littleneck and *Macoma* spp. clam shells throughout the length of the cores (Figure 3.3a). This layer occurred from 1.5 to 2.0 ft. BSS to the bottom of the core. A very distinct wet, coarse-sand layer was present between 5.0 to 7.0 ft. BSS at Stations D3, D8, E7, and F3 (Figure 3.3b). Wood debris was uncommon in the subsurface cores, but was observed in the B6-6 SUB core.

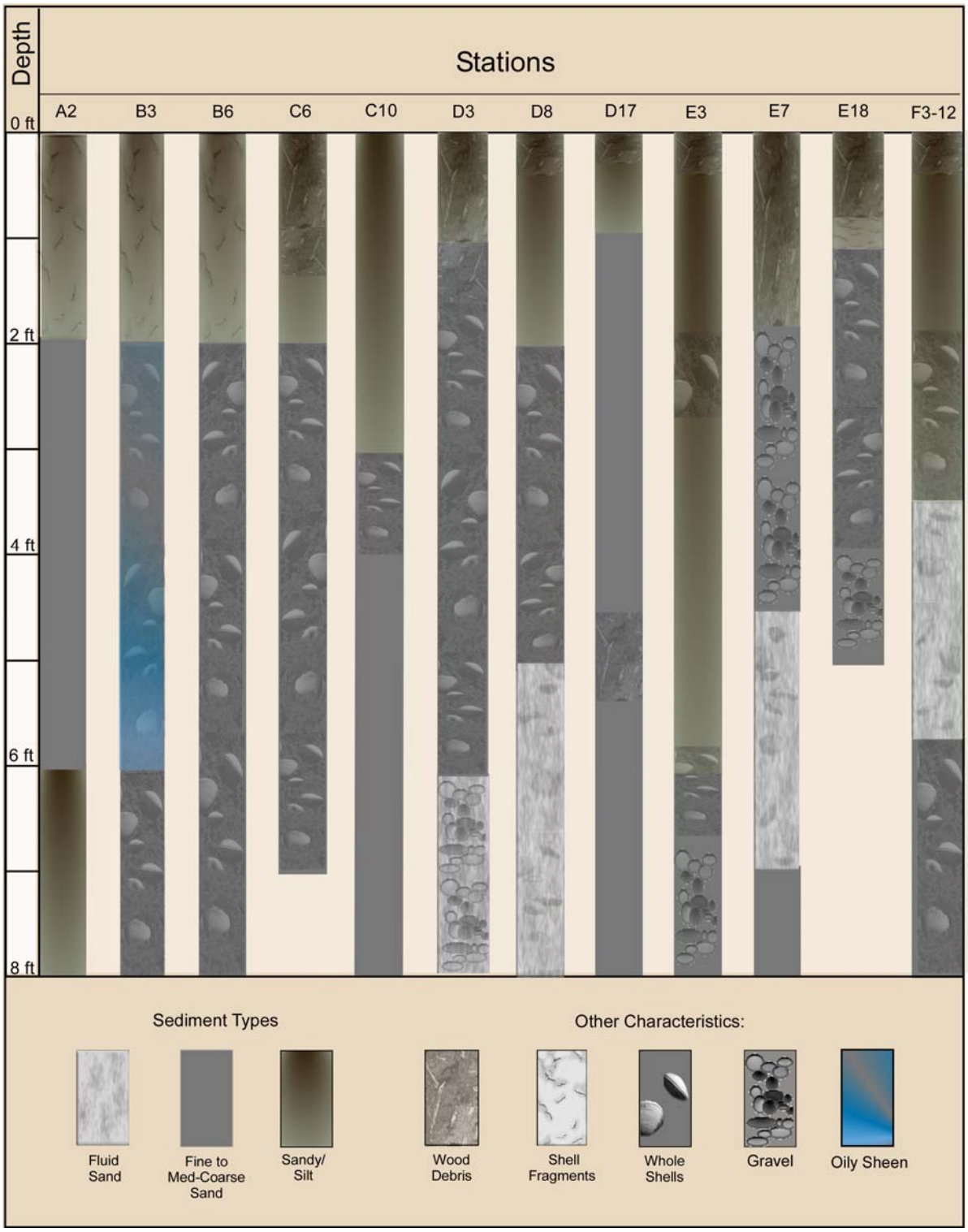
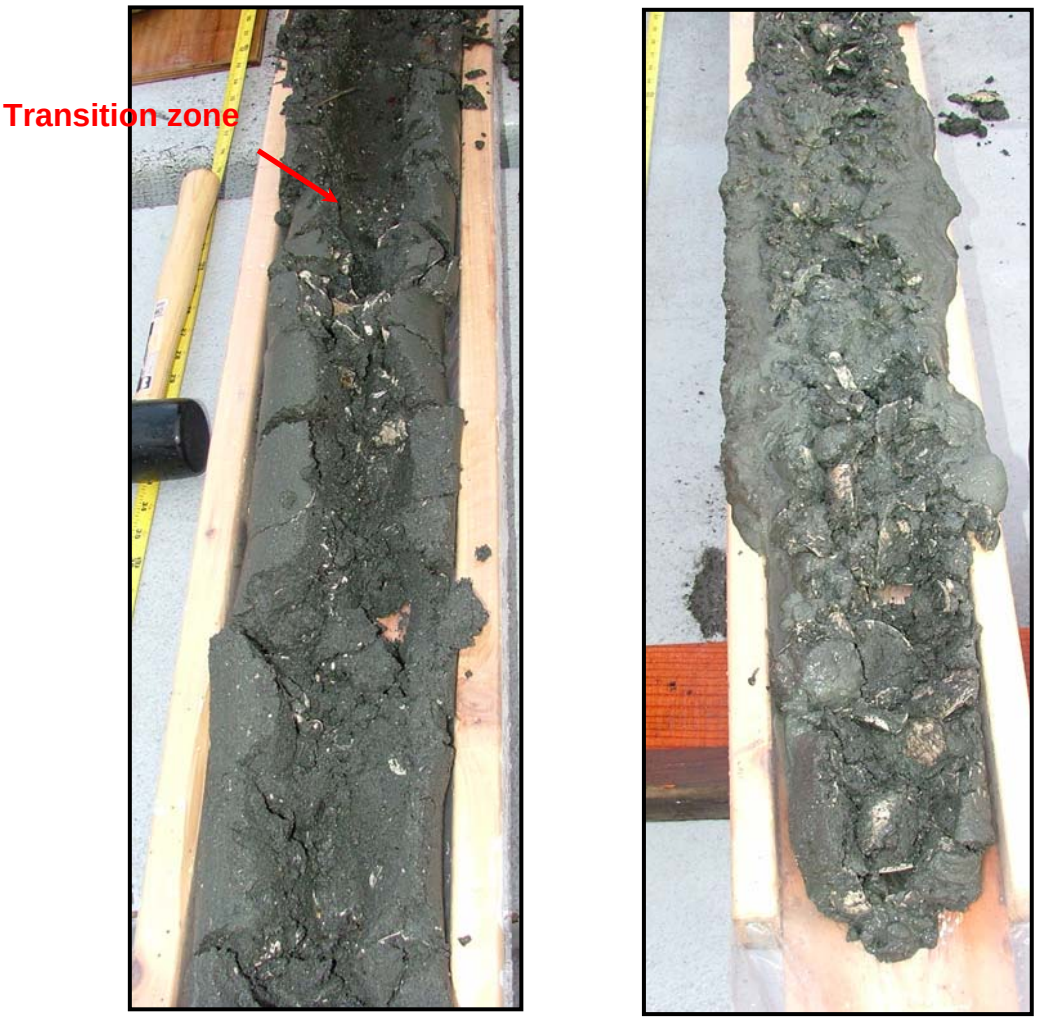


Figure 3.2. Schematic of sediment core profiles from 12″ stations.



(a) (b)

Figure 3.3. Examples of subsurface samples. (a) typical subsurface sediment featuring dry coarse sand with sporadic clam shells. Note that the transition from darker surface to lighter subsurface is marked with the red arrow. (b) example of the very wet coarse sand layer observed in Stations D3, D8, E7, and F3. Also note the high clam shell density in this core.

With the exception of sample B3, none of the subsurface samples showed evidence of creosote odor or sheen. The subsurface sample from Station B3 had large amounts of a silvery-blue oil sheen in the sediment between 4 ft. and 6 ft. BSS (Figure 3.4) with some evidence of free product in the sample. This sample was from the 12" core, indicating that the oil was not simply at the piling-sediment interface at this station. This did not appear to be creosote, but another type of petroleum product.

Figure 3.4. Oil sheen and free product in subsurface sample (between 4 and 6 ft. BSS) observed at Station B3.

3.2 Pre-Removal Tissue Sampling

Sampling of clam tissue and co-located sediments occurred on November 30, 2004. Tissue samples were collected from each of the three areas within the log yard, as well as from the two control sites. The location of each of the tissue samples is presented in Table 3.2 and Figures 3.5 and 3.6. Coordinates for the tissue samples are presented in Appendix C. These stations also represent the locations for control sediment collection.

Native littleneck and Japanese littleneck clams (*P. staminea* and *T. japonica*) were plentiful both near the pilings and in areas away from the pilings; however, their distribution throughout the log yard was patchy. The lower tidal elevations (below – 1.5 ft MLLW) appeared to be at the lower end of their distribution and they were difficult to locate at Station I pilings. Sediment substrate also varied in the log yard,

with the softer, silt-clay sediment occurring between rows of pilings, which also had low clam densities. *Macoma* spp. and cockles were more common in these areas; however, they were not included in clam samples in order to ensure consistency in bioaccumulative potential between samples.

Table 3.2 Station locations for tissue samples and co-located sediments.

Station	Coordinates (NAD 1927)		Samples Collected
	Latitude	Longitude	
TG-6	**	**	Piling C1, C2, C4, D13 and D14
TG-24	**	**	Piling C1, C2, C4, D13 and D14
TG-48	**	**	Between Piling C2-C3 and C3-C4
TH-6	**	**	Piling C7, C8, and D18
TH-24	**	**	Piling C7, C8, and D18
TH-48	**	**	Between Piling C7-C8 and C8-C9
TI-6	**	**	Piling D9, D10, and B6
TI-24	**	**	Piling D9, D10, and B6
TI-48	**	**	Between Piling D9-10 and B6
Control 1-1	48° 01 37.61	123° 00 20.23	~150 m west of the log yard
Control 1-2	48° 01 37.97	123° 00 19.39	~150 m west of the log yard
Control 1-3	48° 01 36.83	123° 00 18.73	~150 m west of the log yard
Control 1-4	48° 01 36.83	123° 00 20.71	~150 m west of the log yard
Control 1-7	48° 01 32.15	123° 00 18.31	~150 m west of the log yard
Control 1-8	48° 01 65.33	123° 00 64.54	~150 m west of the log yard
Control 2-1	48° 01 33.95	122° 59 54.73	Near Jamestown Tribal Center
Control 2-2	48° 01 33.71	122° 59 54.61	Near Jamestown Tribal Center
Control 2-3	48° 01 34.49	122° 59 54.73	Near Jamestown Tribal Center
Control 2-4	48° 01 35.03	122° 59 55.21	Near Jamestown Tribal Center
Control 2-5	48° 01 35.99	122° 59 54.79	Near Jamestown Tribal Center
Control 2-6	48° 01 36.59	122° 59 55.33	Near Jamestown Tribal Center

** Coordinates for locations contributing to this station in Appendix C.

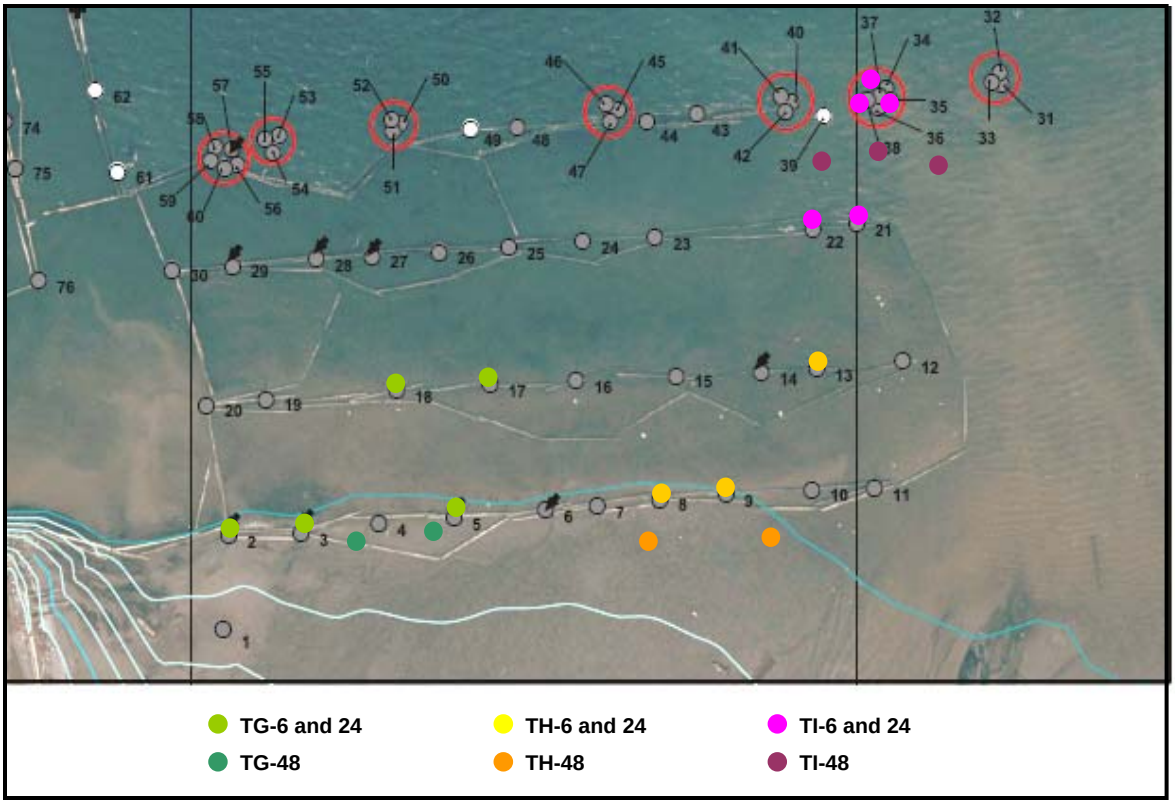


Figure 3.5. Sampling locations for tissue samples and co-located sediments in the log yard.

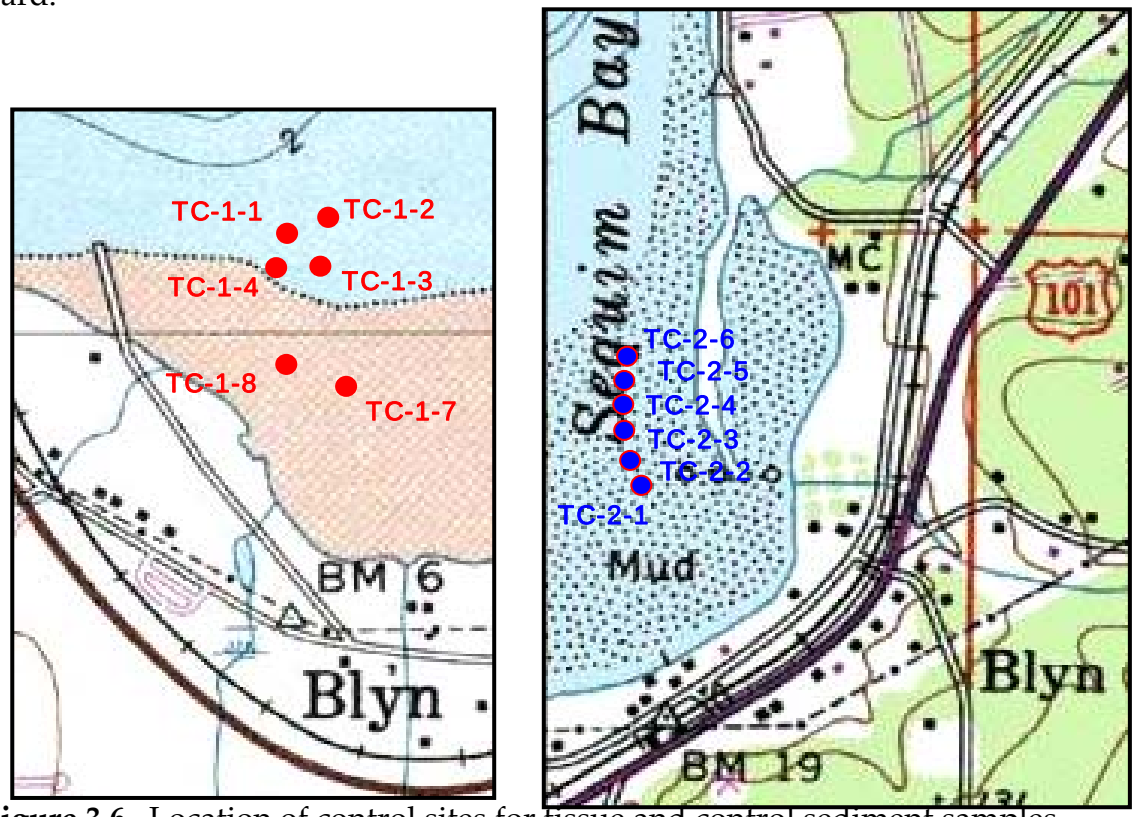


Figure 3.6. Location of control sites for tissue and control sediment samples.

3.3 Pre-removal Analytical Results

Surface and subsurface sediment samples from the log yard and the control sites were analyzed for PAHs and TOC. Clam tissues were analyzed for PAHs and lipids. This section includes results for each of the sediment cores collected from the 2", 6" and 12" Stations, the surficial sediment composites collected with the tissue samples, and the clam tissue chemistry. This survey did not capture the PAH concentrations for sediments in direct contact with the pilings, but did capture sediment from within ½" from the piling.

3.3.1 Sediment Chemistry

All log yard sediment samples were analyzed for total PAHs using ELISA as a screen for PAHs. With the exception of the subsurface samples, all samples contained detected levels of PAHs and were subsequently analyzed for PAHs using GC/MS. Results of the ELISA test are presented in Appendix D. It is important to note that Total PAHs are calculated as the sum of the detected values plus one-half of the detection limits. This is a value that is generally agreed upon for the management of PAHs in the environment and is considered a conservative estimate. The basis for this calculation is that PAHs may be present in a sample at or below the limit of chemical detection. The ½ DL value is a compromise between being overly conservative and not conservative enough.

3.3.1.1 Contol Sediment Chemistry

The control sediment chemistry provided an indication of the level of PAH contamination that existed prior to piling removal. This allowed for a determination of whether the areas currently harvested by the Tribe were affected by piling removal.

PAH and TOC concentrations for the control, or background, sediments collected from the two control stations are presented in Table 3.3. With the exception of Station TC2-6, no PAHs were detected in any of the control sediments. Sediment from Station TC2-6 contained detected concentrations of fluoranthene, pyrene, and chrysene; however each was detected at concentrations just above the detection limit.

Table 3.3 PAH and TOC Concentration in Control Sediment

Analyte	Stations											
	Control Site 1						Control Site 2					
	TC-1-3		TC1-7		TC1-8		TC2-1		TC2-3		TC2-6	
TOC (%)	**0.79**		**0.43**		**1.29**		**0.61**		**0.74**		**0.87**	
PAHs (µg/kg))												
Naphthalene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
2-Methylnaphthalene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Acenaphthylene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Acenaphthene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Fluorene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Phenanthrene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Anthracene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Fluoranthene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	**14**	
Pyrene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	**15**	
Benz(a) anthracene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Chrysene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	**9.3**	
Benzo (b) flouranthene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Benzo (k) fluoranthene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Benzo (a) pyrene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Indeno (1,2,3 –cd) pyrene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Dibenz (a, h) anthracene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Benzo (g, h, I) perylene	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Dibenzofuran	8.7	U	8.3	U	9.1	U	7.6	U	7.8	U	8.4	U
Total Potential PAH	78.3		74.7		81.9		68.4		70.2		101.3	

Bold: Detected value.
U = Undetected. Value at or below reported concentration.

3.3.1.2 Surface Sediment in Cores

PAHs were detected in most of the surface sediment in cores collected from the immediate vicinity of the pilings (Table 3.4). All PAH laboratory bench sheets are presented in Appendix E. The total PAH concentrations were generally highest in the sediments that were closest to the pilings (2″ samples) with concentrations ranging from 1,261 µg/kg dw (Station C6-2) to 386,726 µg/kg dw (Station E3-2). Concentrations of PAHs were lowest in the 12″ samples, with concentrations ranging from 59 µg/kg dw (Station D17-12) to 5,258 µg/kg dw (Station B3-12). The significance of these PAH concentrations will be discussed in Sections 6 and 7; however, it is worth noting that PAH concentrations were below Washington State Sediment Quality Criteria in each of the surface sediment samples collected from the 12″ stations.

PAH concentrations decreased with increased distance from the pilings. With the exception of Stations A2 and E7, the 2″ stations had higher total PAH concentrations than the corresponding 6″ stations, with the ratio of concentrations ranging from 1.13 to 235 times higher in the 2″ stations (Table 3.5). In each case, the 12″ stations had lower concentrations than the 2″ stations, with ratios ranging from 2.7 to >325. There were no statistically significant differences in total PAH concentrations observed in the 6″ stations or 12″ stations, relative to the 2″ stations. This was presumably due to the high variability of concentrations within groups. Station B3 had oil present in the 12″ subsurface sample, indicating that for this station, the elevated PAH concentrations are not likely to be limited to the immediate vicinity of the pilings.

In general, the distribution of PAHs was patchy across the log yard. For the 2″ and 6″ samples there did not appear to be trends between types of pilings (dolphins vs. single pilings) or extent of visible creosote (Table 3.6). Some of the highest PAH concentrations were observed at both dolphins (B3) and single pilings (E3). For the 12″ samples there did appear to be higher concentrations in those samples collected from the dolphins, relative to the single pilings. This may be an indication that the area of influence of these structures is slightly larger. Pilings considered to be heavily creosoted based on visual observation of the above–water portion of the pilings (D3, D17, and E7) had low to moderate total PAH concentrations; whereas pilings not considered to be heavily creosoted (E3 and B3) had the highest total PAH concentrations. This may indicate that there is no relationship between piling appearance and sediment PAH concentrations. However, this could also indicate that pilings which appear to be weathered and less heavily creosoted (based on the above-water observations) may be related to creosote that has sloughed or lost into the sediments.

Average PAH concentrations in sediment collected from the intertidal pilings (B6, C6, C10, D17, and F3) were lower than those of subtidal pilings; however there were no statistically significant differences due to the high variability in the concentrations observed in the subtidal stations. Sediment from the 2″ stations in Area C had the lowest average PAH concentrations of the six areas sample. Average PAH concentrations in sediment from 6″ stations were lowest in Areas C, D, and F. The differences between areas and between intertidal and subtidal stations were driven primarily by hot spots at stations B3 and E3, with total PAH concentrations >300,000 µg/kg dw. Trends between location were greatly diminished when these stations were considered outliers (Table 3.7). PAHs in the 12″ stations were fairly consistent in the log pond with the exception of Areas A and B.

The composition of the PAHs observed in the log yard surface sediment samples was dominated by phenanthrene, fluoranthene, and pyrene (Figure 3.7), with the relative contribution of other PAHs such as naphthalene, acenaphthene, and chrysene increasing in samples with lower total PAH concentrations.

Table 3.4 PAH Concentrations in Surface Samples of Sediment Cores, Jimmycomelately Creek Log Yard

Analytes	Surface Samples from Core Stations								
	A2-2 [a]	A2-6 [a]	A2-12 [a]	B3-2	B3-6	B3-12	B6-2	B6-6	B6-12
TOC (%)	1.11	1.09		2.79	0.84		0.62	3.20	
PAHs (µg/kg dw)									
Naphthalene	**11**	**9.6**	**7.0**	**2300**	6.5 U	**390**	6.6 U	**1200**	**31**
2-Methylnaphthalene	**14**	6.4 U	6.4 U	**350**	6.5 U	**130**	6.6 U	6.6 U	**9.7**
Acenaphthylene	**52**	**65**	**8.9**	**530**	**87**	**18**	**32**	6.6 U	**7.8**
Acenaphthene	**83**	**190**	**80**	**16000**	**160**	**200**	**44**	6.6 U	**16**
Fluorene	**140**	**230**	**120**	**22000**	**120**	**140**	**88**	**22**	**9.7**
Phenanthrene	**1700**	**2800**	**840**	**90000**	**2400**	**420**	**910**	**26**	**180**
Anthracene	**300**	**210**	**96**	**5200**	**420**	**91**	**61**	6.6 U	**30**
Fluoranthene	**5700**	**7100**	**1300**	**92000**	**12000**	**1800**	**3000**	**76**	**710**
Pyrene	**4000**	**3900**	**810**	**52000**	**7800**	**1100**	**1800**	**56**	**510**
Benz(a) anthracene	**690**	**510**	**150**	**6600**	**940**	**180**	**240**	6.6 U	**110**
Chrysene	**1400**	**1200**	**280**	**12000**	**2300**	**370**	**640**	**18**	**180**
Benzo (b) fluoranthene	**480**	**500**	**100**	**4400**	**640**	**120**	**240**	**7.3**	**89**
Benzo (k) fluoranthene	**350**	**330**	**76**	**4000**	**540**	**94**	**170**	6.6 U	**68**
Benzo (a) pyrene	**220**	**160**	**48**	**2100**	**270**	**50**	**77**	6.6 U	**39**
Indeno (1,2,3 –cd) pyrene	**68**	**59**	**16**	**570**	**93**	**18**	**28**	6.6 U	**14**
Dibenz (a, h) anthracene	**23**	**22**	6.4 U	**180**	**33**	6.5 U	6.6 U	6.6 U	6.5 U
Benzo (g, h, I) perylene	**61**	**53**	**13**	**480**	**79**	**14**	**27**	6.6 U	**13**
Dibenzofuran	**70**	**140**	**62**	**13000**	**64**	**120**	**47**	**24**	**8.4**
Total PAH[1]	**15,362**	**17,482**	**4,013**	**323,710**	**27,953**	**5,258**	**7,414**	**1,462**	**2,029**

Table 3.4 Continued.

Analytes	Surface Samples from Core Stations								
	C6-2 [a]	C6-6 [a]	C6-12 [a]	C10-2	C10-6	C10-12	D3-2	D3-6	D3-12
TOC (%)	2.91	1.32		1.98	1.88		4.42	3.47	
PAHs (µg/kg dw)									
Naphthalene	6.4 U	6.4 U	6.6 U	**11**	6.5 U	NA	6.5 U	**8.0**	**18**
2-Methylnaphthalene	6.4 U	6.4 U	6.6 U	6.6 U	6.5 U	NA	6.5 U	6.7 U	6.4 U
Acenaphthylene	6.4 U	6.4 U	6.6 U	6.6 U	6.5 U	NA	**51**	6.7 U	6.4 U
Acenaphthene	6.4 U	6.4 U	6.6 U	**7.9**	6.5 U	NA	**46**	6.7 U	6.4 U
Fluorene	6.4 U	6.4 U	6.6 U	**9.2**	6.5 U	NA	**60**	6.7 U	6.4 U
Phenanthrene	**26**	6.4 U	**16**	**340**	**14**	NA	**710**	**37**	**15**
Anthracene	**9.6**	6.4 U	6.6 U	**9.9**	6.5 U	NA	**230**	**13**	**11**
Fluoranthene	**360**	**42**	**48**	**470**	**120**	NA	**6800**	**350**	**130**
Pyrene	**240**	**60**	**110**	**390**	**190**	NA	**4600**	**380**	**230**
Benz(a) anthracene	**82**	**17**	**24**	**41**	**22**	NA	**1100**	**79**	**42**
Chrysene	**190**	**33**	**44**	**88**	**40**	NA	**2200**	**150**	**85**
Benzo (b) fluoranthene	**130**	**32**	**37**	**29**	**18**	NA	**780**	**75**	**45**
Benzo (k) fluoranthene	**130**	**23**	**37**	**29**	**18**	NA	**840**	**70**	**38**
Benzo (a) pyrene	**51**	**9.0**	**18**	**14**	**9.8**	NA	**460**	**38**	**22**
Indeno (1,2,3 –cd) pyrene	**17**	6.4 U	6.6 U	6.6 U	6.5 U	NA	**150**	**15**	**7.7**
Dibenz (a, h) anthracene	**8.9**	6.4 U	6.6 U	6.6 U	6.5 U	NA	**60**	6.7 U	6.4 U
Benzo (g, h, I) perylene	**16**	6.4 U	6.6 U	6.6 U	6.5 U	NA	**140**	**13**	6.4 U
Dibenzofuran	6.4 U	6.4 U	6.6 U	6.6 U	6.5 U	NA	**21**	6.7 U	6.4 U
Total PAH	**1,280**	**251**	**489**	**1,459**	**464**	**NA**	**18,255**	**1,248**	**666**

Table 3.4 Continued.

Analytes	Surface Samples from Core Stations								
	D17-2	D17-6	D17-12	E3-2	E3-6	E3-12	E7-2 [a]	E7-6 [a]	E7-12 [a]
TOC (%)	2.39	0.596		3.51	2.28		2.78	2.62	
PAHs (µg/kg dw)									
Naphthalene	6.4 U	6.6 U	6.6 U	**53**	6.4 U	**8.3**	6.4 U	**36**	NA
2-Methylnaphthalene	6.4 U	6.6 U	6.6 U	**53**	6.4 U	6.4 U	6.4 U	**61**	NA
Acenaphthylene	**61**	6.6 U	6.6 U	**980**	**56**	**7.0**	**12**	**59**	NA
Acenaphthene	**73**	**14**	6.6 U	**2200**	**30**	6.4 U	**15**	**32**	NA
Fluorene	**46**	**16**	6.6 U	**560**	**52**	6.4 U	**23**	**340**	NA
Phenanthrene	**1000**	6.6 U	6.6 U	**14000**	**730**	**15**	**180**	**820**	NA
Anthracene	**160**	6.6 U	6.6 U	**3300**	**110**	**8.3**	**38**	**2400**	NA
Fluoranthene	**5600**	**11**	6.6 U	**190000**	**6300**	**530**	**560**	**4500**	NA
Pyrene	**3500**	**13**	6.6 U	**110000**	**39000**	**400**	**840**	**3800**	NA
Benz(a) anthracene	**360**	6.6 U	6.6 U	**9800**	**450**	**34**	**130**	**450**	NA
Chrysene	**950**	6.6 U	6.6 U	**26000**	**1200**	**99**	**270**	**1100**	NA
Benzo (b) fluoranthene	**390**	6.6 U	6.6 U	**14000**	**350**	**42**	**110**	**350**	NA
Benzo (k) fluoranthene	**290**	6.6 U	6.6 U	**12000**	**350**	**32**	**82**	**350**	NA
Benzo (a) pyrene	**120**	6.6 U	6.6 U	**2000**	**140**	**12**	**50**	**180**	NA
Indeno (1,2,3 –cd) pyrene	**44**	6.6 U	6.6 U	**750**	**56**	6.4 U	**21**	**77**	NA
Dibenz (a, h) anthracene	**13**	6.6 U	6.6 U	**210**	**22**	6.4 U	6.4 U	**20**	NA
Benzo (g, h, I) perylene	**43**	6.6 U	6.6 U	**620**	**48**	6.4 U	**21**	**75**	NA
Dibenzofuran	**18**	6.6 U	6.6 U	**200**	**25**	6.4 U	**14**	**100**	NA
Total PAH	**12,674**	**100**	**59**	**386,726**	**48,925**	**1,210**	**2,376**	**14,750**	**NA**

Table 3.4 Continued.

Analytes	E18-2	E18-6	E18-12	F3-2	F3-6	F3-12
TOC (%)	0.779	0.878		15.1	6.97	
PAHs (µg/kg dw)						
Naphthalene	6.6 U	6.5 U	6.6 U	**24**	**8.9**	6.2 U
2-Methylnaphthalene	6.6 U	6.5 U	6.6 U	**24**	6.8 U	6.2 U
Acenaphthylene	**9.3**	**9.7**	6.6 U	**24**	6.8 U	6.2 U
Acenaphthene	**29**	**11**	6.6 U	**55**	**73**	6.2 U
Fluorene	**64**	**16**	6.6 U	**24**	6.8 U	6.2 U
Phenanthrene	**640**	**200**	**14**	**120**	**17**	6.2 U
Anthracene	**22**	**28**	6.6 U	**100**	6.8 U	6.2 U
Fluoranthene	**820**	**880**	**56**	**2100**	**37**	**17**
Pyrene	**580**	**650**	**33**	**1100**	**22**	**12**
Benz(a) anthracene	**64**	**77**	**13**	**260**	6.8 U	6.2 U
Chrysene	**160**	**210**	**13**	**390**	6.8 U	6.2 U
Benzo (b) fluoranthene	**54**	**71**	**7.3**	**130**	6.8 U	6.2 U
Benzo (k) fluoranthene	**45**	**59**	**5.3 J**	**150**	6.8 U	6.2 U
Benzo (a) pyrene	**19**	**21**	6.6 U	**70**	6.8 U	6.2 U
Indeno (1,2,3 –cd) pyrene	**8**	**8.4**	6.6 U	**27**	6.8 U	6.2 U
Dibenz (a, h) anthracene	6.6 U	6.5 U	6.6 U	**24**	6.8 U	6.2 U
Benzo (g, h, I) perylene	6.6 U	**8.4**	6.6 U	**25**	6.8 U	6.2 U
Dibenzofuran	**33**	**9.7**	6.6 U	**24**	6.8 U	6.2 U
Total Potential PAH	**2,561**	**2,269**	**178**	**4,599**	**202**	**79**

[a] Heavily creosoted pilings

NA: Not analyzed.

[1] Total PAHs calculated as the sum of all detected values plus one-half of each undetected value.

U: Undetected – actual concentration is at or below the reported value.

Table 3.5 Summary of Total PAH Concentrations in Surface Samples

Station	Total PAH (µg/kg dw)			Ratio	
	2"	6"	12"	2":6"	2":12"
A2	15,362	17,482	4,013	0.88	**3.8**
B3	323,710	27,953	5,258	**12**	**62**
B6	7,414	1,462	2,029	**5.2**	**3.7**
C6	1,280	251	489	**5.8**	**2.7**
C10	1,459	464	NA	**3.3**	NC
D3	18,255	1,248	666	**15**	**28**
D17	12,674	100	59	**235**	**215**
E3	386,726	48,925	1,210	**7.9**	**325**
E7	2,376	14,750	NA	0.16	NA
E18	2,561	2,269	178	**1.1**	**18**
F3	4,599	202	79	**29**	**156**
Mean	70,569	10,443	1,527	**29**	**90**
SD	141,558	15,832	1,898	68.8	116
CV	200%	150%	120%	240%	128%

Bold: Ratio greater than 1.0.

Table 3.6 Summary Statistics for Strata

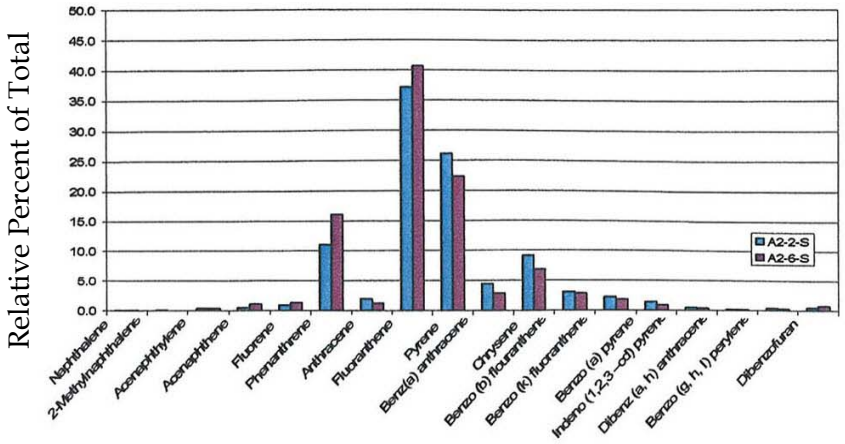
Strata	2" Stations		6" Stations		12" Stations	
	Average	SD	Average	SD	Average	SD
A	15,362	NC	17,482	NC	4,013	NC
B	165,562	223,655	14,707	18,731	3,644	2283
C	1,369	127	358	151	489	NC
D	15,464	3,946	674	812	363	429
E	130,554	22,851	21,981	24,154	694	730
F	4,599	NC	202	NC	79	NC
Single Pilings	53,741	134,686	8,526	17,058	447	445
Dolphins	169,536	180,363	22,717	13,342	3,767	1,629
Shallow	7,613	6,723	621	585	323	302
Deep	146,147	192,223	22,276	17,481	2,537	2,071

Table 3.7 Summary Statistics for Strata, with B3 and E3 removed

Strata	2" Stations		6" Stations		12" Stations	
	Average	SD	Average	SD	Average	SD
A	15,362	NC	17,482	NC	4,013	NC
B	**7,414**	**NC**	**1,462**	**NC**	**2,029**	**NC**
C	1,369	127	358	151	489	NC
D	15,464	3,946	674	812	363	429
E	**2,468**	**26,704**	**8,509**	**7941**	**178**	**NC**
F	4,599	NC	202	NC	79	NC
Single Pilings	**6,172**	**6,638**	**2,755**	**5,346**	**294**	**270**
Dolphins	**11,388**	**5,620**	**9,472**	**11,327**	**3,021**	**1402**
Shallow	7,613	6,723	621	585	323	302
Deep	**6,766**	**11,500**	**7,445**	**8,110**	**2,073**	**1,918**

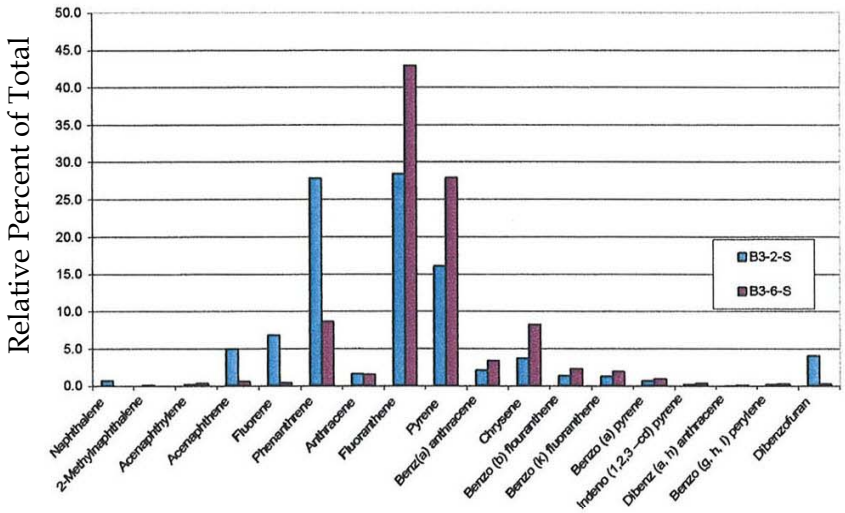
Bold: Mean values that have changed with the exclusion of B3 and E3.
NC: Not calculable, only one value.

Relative PAH Distribution – A2



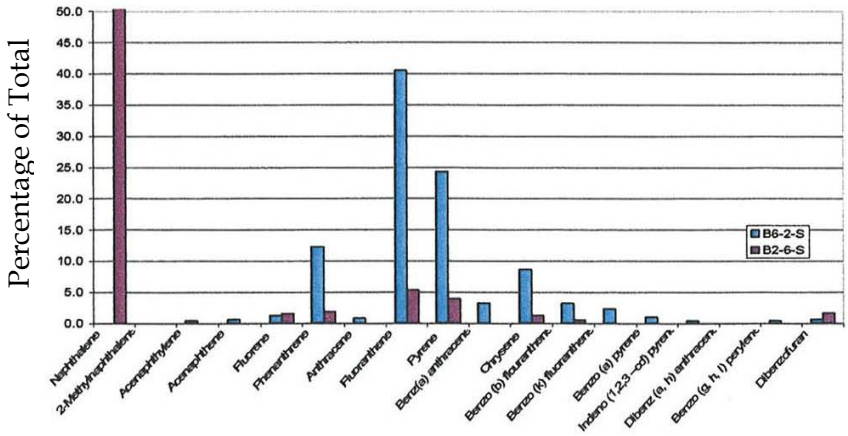
$\sum_{A2\text{-}2}$ = 15362 µg/Kg DW
$\sum_{A2\text{-}6}$ = 17479 µg/Kg DW

Relative PAH Distribution – B3



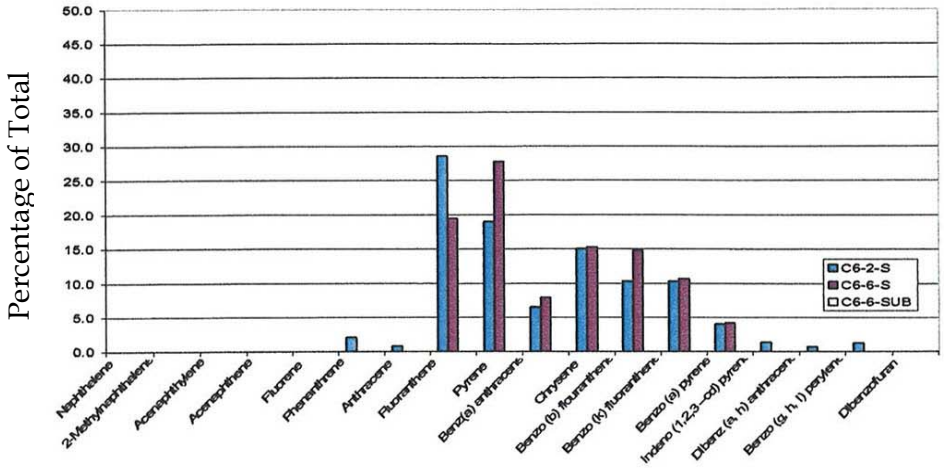
$\sum_{B3\text{-}2}$ = 323710 µg/Kg DW
$\sum_{B3\text{-}6}$ = 27946 µg/Kg DW

Relative Distribution of PAHs – B6



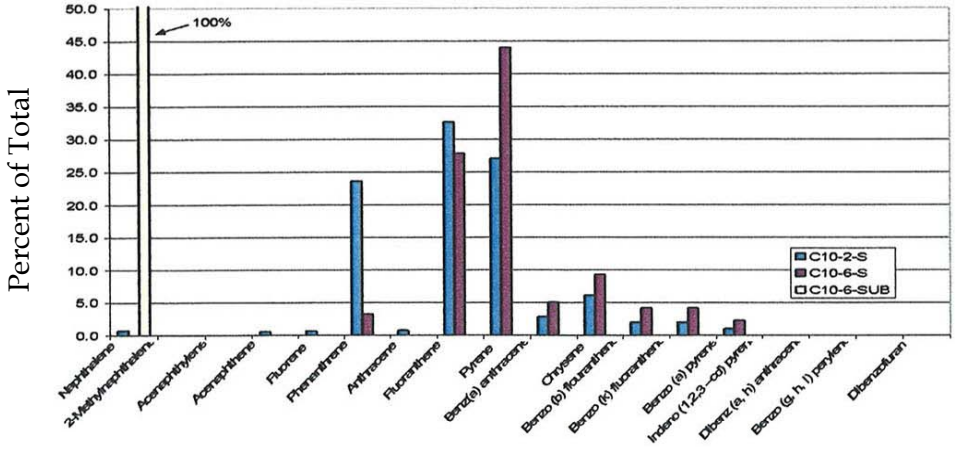
$\sum_{B6\text{-}2}$ = 7404 µg/Kg DW
$\sum_{B6\text{-}6}$ = 1429 µg/Kg DW

Relative Distribution of PAHs – C6



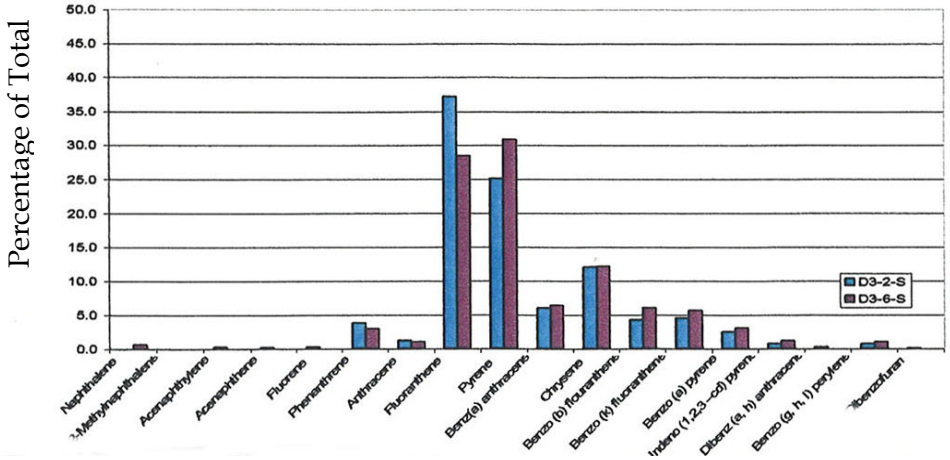
$\sum_{C6\text{-}2}$ = 1261µg/Kg DW
$\sum_{C6\text{-}6}$ = 216 µg/Kg DW
$\sum_{C6\text{-}6\ SUB}$= 0 µg/Kg DW

Relative Distribution of PAHs – C10



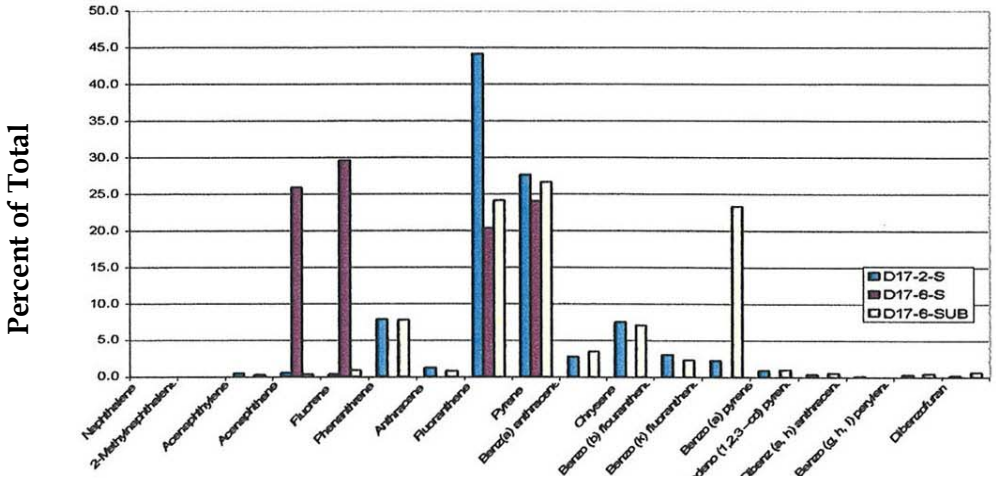
$\sum_{C10\text{-}2}$ = 1439µg/Kg DW
$\sum_{C10\text{-}6}$ = 432 µg/Kg DW
$\sum_{C10\text{-}6\ SUB}$= 83 µg/Kg DW

Relative Distribution of PAHs – D3



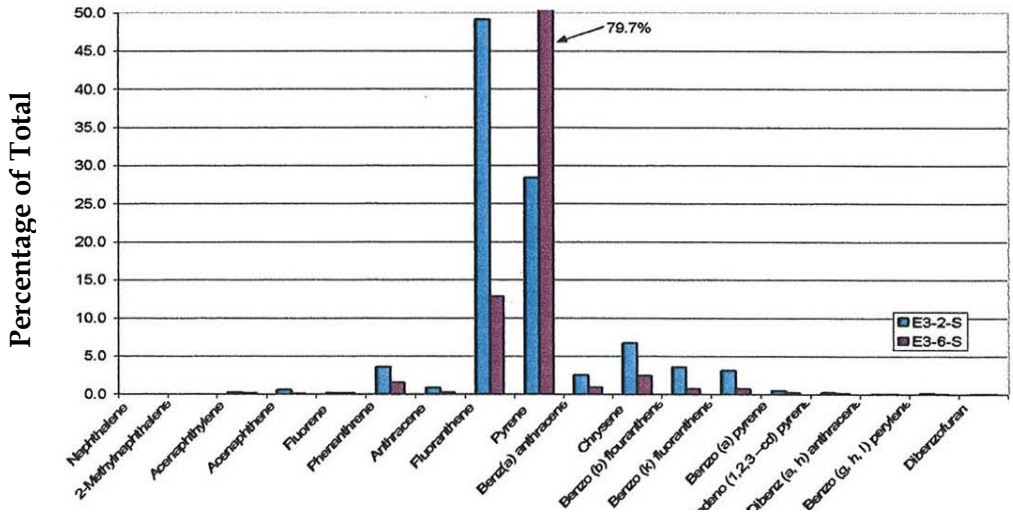
$\sum_{D3\text{-}2}$ = 18248µg/Kg DW
$\sum_{D3\text{-}6}$ = 1228 µg/Kg DW

Relative Distribution of PAHs – D17



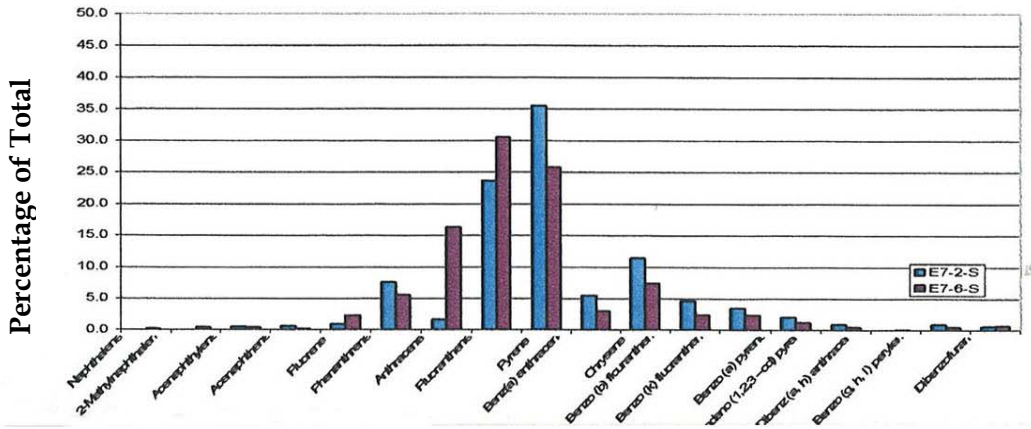
$\sum_{D17\text{-}2}$ = 12668µg/Kg DW
$\sum_{D17\text{-}6}$ = 54 µg/Kg DW
$\sum_{D17\text{-}6\ SUB}$= 2814 µg/Kg DW

Relative distribution of PAHs – E3



$\sum_{E3\text{-}2}$ = 386726µg/Kg DW
$\sum_{E3\text{-}6}$ = 48919µg/Kg DW

Relative Distribution of PAHs – E7



$\sum_{E7\text{-}2}$ = 2366µg/Kg DW
$\sum_{E7\text{-}6}$ = 14750 µg/Kg DW

3.3.1.2 Subsurface Sediment

Measured concentrations of PAHs and TOC for subsurface samples collected from the 6″ stations accessible at low tide and 12″ stations collected with the vibracorer are presented in Table 3.8.

Subsurface samples were generally lower than the surface samples with all stations, with the exception of B3-12, which contained free product in the subsurface sample. Concentrations of total PAHs in samples (excluding B6-6) ranged from 58 µg/kg and 2,824 µg/kg dw. Station B6 was not included in further sample analysis because there were numerous chunks of creosoted wood contaminating the sample. PAH concentrations in the subsurface samples were statistically significantly lower than those of the corresponding surface samples.

Table 3.8 PAH Concentrations observed in Subsurface Sediments, Jimmycomelately Creek Log Yard

Analytes	A2-12	B3-12	C6-6	C10-6	D3-12	D8-6	D17-6	D17-12	E7-12	E18- 12	F3-6	F3-12
TOC (%)			0.87	1.16	2.8	0.99	2.8				3.36	
PAHs (µg/kg))												
Naphthalene	6.3 U	**16000**	6.6U	**83**	13	6.4 U	6.6 U	6.6 U	6.5 U	6.5 U	**680**	6.3 U
2-Methylnaphthalene	6.3 U	**4700**	6.6 U	6.5 U	6.4 U	6.4 U	6.6 U	6.6 U	6.5 U	6.5 U	**35**	6.3 U
Acenaphthylene	6.3 U	**47**	6.6U	6.5 U	6.4 U	6.4 U	**7.9**	**11**	6.5 U	6.5 U	6.4 U	6.3 U
Acenaphthene	6.3 U	**5500**	6.6 U	6.5 U	6.4 U	6.4 U	**11**	6.6 U	6.5 U	6.5 U	**490**	6.3 U
Fluorene	6.3 U	**5000**	6.6 U	6.5 U	6.4 U	6.4 U	**25**	6.6 U	6.5 U	6.5 U	**250**	6.3 U
Phenanthrene	**6.9**	**13000**	6.6 U	6.5 U	6.4 U	**24**	**220**	**82**	6.5 U	6.5 U	**420**	6.3 U
Anthracene	6.3 U	**1100**	6.6 U	6.5 U	6.4 U	6.4 U	**24**	**22**	6.5 U	6.5 U	**49**	6.3 U
Fluoranthene	6.3 U	**5300**	6.6 U	6.5 U	6.4 U	**28**	**680**	**1300**	6.5 U	6.5 U	**220**	6.3 U
Pyrene	6.3 U	**3000**	6.6 U	6.5 U	6.4 U	**22**	**750**	**720**	6.5 U	6.5 U	**140**	6.3 U
Benz(a) anthracene	6.3 U	**630**	6.6 U	6.5 U	6.4 U	6.4 U	**98**	**65**	6.5 U	6.5 U	**29**	6.3 U
Chrysene	6.3 U	**600**	6.6 U	6.5 U	6.4 U	6.4 U	**200**	**200**	6.5 U	6.5 U	**31**	6.3 U
Benzo (b) flouranthene	6.3 U	**2200**	6.6 U	6.5 U	6.4 U	6.4 U	**66**	**78**	6.5 U	6.5 U	**9.6**	6.3 U
Benzo (k) fluoranthene	6.3U	**140**	6.6 U	6.5 U	6.4 U	6.4 U	**656**	**51**	6.5 U	6.5 U	**8.3**	6.3 U
Benzo (a) pyrene	6.3 U	**110**	6.6 U	6.5 U	6.4 U	6.4 U	**30**	**16**	6.5 U	6.5 U	6.4 U	6.3 U
Indeno (1,2,3 –cd) pyrene	6.3 U	**26**	6.6U	6.5 U	6.4 U	6.4 U	**16**	**7.3**	6.5 U	6.5 U	6.4 U	6.3 U
Dibenz (a, h) anthracene	6.3 U	**11**	6.6 U	6.5 U	6.4 U	6.4 U	6.6 U	6.6 U	6.5 U	6.5 U	6.4 U	6.3 U
Benzo (g, h, I) perylene	6.3 U	**21**	6.6 U	6.5 U	6.4 U	6.4 U	**12**	6.6 U	6.5 U	6.5 U	6.4 U	6.3 U
Dibenzofuran	6.3 U	**4200**	6.6 U	6.5 U	6.4 U	6.4 U	**18**	6.6 U	6.5 U	6.5 U	**260**	6.3 U
Total PAH	**60**	**61,585**	**59**	**138**	**67**	**122**	**2,824**	**2,552**	**58**	58	**2,623**	57

U: Undetected – actual concentration is at or below the reported value.

3.3.1.2 Sediment Chemistry in Support of the Risk Assessment

In order to estimate both the environmental risk and the human health risk in the area around the pilings, average concentrations were calculated using PAH concentrations for both the 2″ stations and 6″ stations. It was assumed that as the pilings are pulled, only that sediment within 6″ will be potentially mobilized. The "adjusted" PAH concentration was a weighted mean of the 2″ and 6″ stations, using the relative contributions to the total volume or area.

Based on inner and outer radii represented by the 2″ and 6″ stations (0.5″ to 3.5″ and 4.5″ to 7.5″, respectively) and the surface sediment depth of two feet, the volume represented by the 2″ station was 0.099 m^3, or 42% of the total volume. The estimated volume represented by the 6″ station was 0.138 m^3, or 58% of the total volume. The calculated PAH concentrations expected in sediment within approximately 6″ of the pilings are presented in Table 3.10.

3.3.1.3 Surficial Sediment Chemistry

PAH and TOC concentrations for the surficial sediment composites collected in the log yard at stations co-located with the tissue samples are presented in Table 3.11. Total detected PAH concentrations ranged from 0.0 µ/kg to 7,726 µg/kg. In each area (G, H, and I) the PAH concentrations decreased with distance from the piling, with few detected PAHs observed in the sediment collected from greater than 48″ from the piling. As with the core samples, the primary constituents were phenanthrene, fluoranthene, pyrene, and chrysene.

3.3.1 Tissue Chemistry

PAH and lipid concentrations for the clam tissue composites collected in the log yard are presented in Table 3.12. The achieved detection limit for all tissue samples was 10 µg/kg dw. Total detected PAH concentrations ranged from 0.0 µg/kg to 7,726 µg/kg. In each area (G, H, and I) the PAH concentrations decreased with distance from the piling, with few detected PAHs observed in the sediment collected from greater than 48″ from the piling. With the exception of phenanthrene, fluoranthene, and pyrene, detected PAHs were all below 100 µg/kg dw. The highest observed concentration for any consistuents was 350 µg/kg, despite higher concentrations in the co-located sediment.

Table 3.10 Adjusted PAH concentrations based on weighted mean.

Analyte	Adjusted Concentrations										
	A2	B3	B6	C6	E18	D3	D17	E3	E7	F3	C10
TOC (%)	1.1	1.7	2.1	2.0	0.8	3.9	1.3	2.8	2.7	10.4	1.9
PAHs (µg/kg))											
Naphthalene	10.2	962	700	3.2	3.3	6.0	3.3	24.0	22.3	10.2	6.5
2-Methylnaphthalene	7.7	148	3.3	3.2	3.3	3.3	3.3	24.0	36.9	7.0	3.3
Acenaphthylene	59.6	272	15.3	3.2	9.5	23.2	27.4	441.8	39.4	7.0	3.3
Acenaphthene	145	6774	20.3	3.2	18.5	21.2	38.6	936.0	24.9	65.5	5.2
Fluorene	192	9256	49.6	3.2	36.0	27.0	28.5	264.1	208	7.0	5.7
Phenanthrene	2341	38975	395	12.7	384	318	419	6271	553	60.0	150.1
Anthracene	248	2416	27.4	5.9	25.5	104	68.7	1442	1414	43.7	6.0
Fluoranthene	6516	45402	1297	175	855	3043	2345	83000	2855	898	266
Pyrene	3942	26255	784	135	621	2142	1469	68644	2564	472	274
Benz(a) anthracene	585	3303	102	44.1	71.6	505	152	4354	316	110	29.9
Chrysene	1284	6350	278	98.6	189	1006	399	11555	754	165	60.0
Benzo (b) flouranthene	492	2210	104	72.9	63.9	369	165	6049	250	56.3	22.6
Benzo (k) fluoranthene	338	1985	72.9	67.7	53.2	391	123	5214	238	64.6	22.6
Benzo (a) pyrene	185	1034	34.1	26.5	20.2	214.2	52.0	917	125.7	31.2	11.6
Indeno (1,2,3 –cd) pyrene	62.8	292	13.6	9.0	8.2	71.4	20.3	346	53.6	13.3	3.3
Dibenz (a, h) anthracene	22.4	94.4	3.3	5.6	3.3	27.0	7.4	100.5	13.0	7.0	3.3
Benzo (g, h, I) perylene	56.3	246	13.2	8.5	6.3	66.0	19.9	287	52.5	12.4	3.3
Dibenzofuran	111	5465	33.6	3.2	19.4	10.7	9.4	98.1	64.1	7.0	3.3
Total PAH	**16,486**	**145,974**	**3,914**	**677**	**2,371**	**8,338**	**5,341**	**189,868**	**9,519**	**2,031**	**876**

U: Undetected – actual concentration is at or below the reported value.

Table 3.11 PAH and TOC Concentrations in Surficial Sediment in Log Yard

Analyte	TG-6	TG-24	TG-48	TH-6	TH-24	TH-48	TI-6	TI-24	TI-48
TOC (%)	3.39	2.34	3.16	0.955	1.14	0.608	0.405	0.326	0.576
PAHs (µg/kg))									
Naphthalene	10	8.1 U	9.6 U	9.1 U	9.6 U	8.5 U	8.4 U	8.9 U	9.0 U
2-Methylnaphthalene	9.2 U	8.1 U	9.6 U	9.1 U	9.6 U	8.5 U	8.4 U	8.9 U	9.0 U
Acenaphthylene	26	8.1 U	9.6 U	9.1 U	9.6 U	8.5 U	18	12	9.0 U
Acenaphthene	220	8.1 U	9.6 U	16	9.6 U	8.5 U	150	180	9.0 U
Fluorene	150	8.1 U	9.6 U	15	9.6 U	8.5 U	130	230	9.0 U
Phenanthrene	1500	16	9.6 U	100	15	8.5 U	810	860	9.0 U
Anthracene	140	18	9.6 U	18	9.6 U	8.5 U	160	77	9.0 U
Fluoranthene	2800	570	31	290	32	8.5 U	2000	1600	9.0 U
Pyrene	1500	390	91	220	31	8.5 U	870	890	9.9
Benz(a) anthracene	240	57	13	60	12	8.5 U	260	160	9.0 U
Chrysene	540	140	13	130	31	8.5 U	430	320	9.0 U
Benzo (b) flouranthene	220	53	9.6	52	15	8.5 U	180	120	9.0 U
Benzo (k) fluoranthene	160	37	9.6 U	47	14	8.5 U	130	91	9.0 U
Benzo (a) pyrene	86	20	9.6 U	24	9.6 U	8.5 U	73	44	9.0 U
Indeno (1,2,3 –cd) pyrene	28	8.1 U	9.6 U	9.1 U	9.6 U	8.5 U	25	15	9.0 U
Dibenz (a, h) anthracene	9.2 U	8.1 U	9.6 U	9.1 U	9.6 U	8.5 U	8.4 U	8.9 U	9.0 U
Benzo (g, h, I) perylene	23	8.1 U	9.6 U	9.1 U	9.6 U	8.5 U	20	13	9.0 U
Dibenzofuran	83	8.1 U	9.6 U	9.1 U	9.6 U	8.5 U	63	120	9.0 U
Total Potential PAH	7735	1337	220	1004	203	76.5	5332	4738	86.4
Total Measured PAH	7726	1301	225	972	150.0	0.0	5319	4732	9.9

U: Undetected – actual concentration is at or below the reported value.

Table 3.12 PAH and Lipid Concentrations in Clams Collected from the former Log Yard.

Analyte	Stations								
	TG-6	TG-24	TG-48	TH-6	TH-24	TH-48	TI-6	TI-24	TI-48
Lipids (%)	1.12	0.96	1.05	0.98	0.99	0.92	1.10	0.85	1.17
PAHs (µg/kg))									
Naphthalene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
2-Methylnaphthalene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Acenaphthylene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Acenaphthene	10 U	10 U	10 U	**19**	10 U	10 U	10 U	10 U	10 U
Fluorene	**11**	10 U	10 U	**32**	10 U	10 U	**12**	10 U	10 U
Phenanthrene	**72**	10 U	**16**	**140**	10 U	10 U	**90**	**39**	10 U
Anthracene	10 U	10 U	10 U	**23**	10 U	10 U	**14**	10 U	10 U
Fluoranthene	**130**	**13**	**14**	**350**	**20**	10 U	**280**	**83**	10 U
Pyrene	**67**	10 U	10 U	**200**	**24**	10 U	**160**	**47**	10 U
Benz(a) anthracene	10 U	10 U	10 U	**20**	10 U	10 U	**14**	10 U	10 U
Chrysene	10 U	10 U	10 U	**19**	10 U	10 U	**18**	**11**	10 U
Benzo (b) flouranthene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Benzo (k) fluoranthene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Benzo (a) pyrene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Indeno (1,2,3 –cd) pyrene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Dibenz (a, h) anthracene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Benzo (g, h, I) perylene	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Dibenzofuran	10 U	10 U	10 U	**26**	10 U	10 U	10 U	10 U	10 U
Total Potential PAH	**350**	**98**	**110**	**874**	**124**	**90**	**643**	**250**	**90**
Total Measured PAH	**280**	**13**	**30**	**829**	**44**	**0**	**588**	**180**	**0**

U: Undetected – actual concentration is at or below the reported value.

4.0 Results of During-Removal Monitoring

PAH concentrations, total suspended solids, and turbidity were monitored during piling removal. Piling removal events were monitored on July 25, 27, and 28, 2005. There were few successful piling removals on the 25th, so all water samples, TSS, and turbidity data are for pilings pulled on July 27 and 28. The purposes of this monitoring were to evaluate the extent of sediment suspension and redistribution during the piling removal process and to evaluate the PAH concentrations in the water column as a result of removal activities. This monitoring was not conducted in order to make management decisions regarding removal, but was used to help guide post-removal sampling efforts. It was also conducted in response to a concern from US Fish and Wildlife Service that sedimentation from piling removal was a major problem, and the required that a silt curtain be used during removal.

Water samples were collected using a sampling manifold connected to a mooring buoy that was placed within 1 meter of the piling. Samples were collected from depths of 50 cm above bottom (Bottom), 1.5 m above the bottom (Mid), and 1 m below surface (Surface). Control samples were collected at a depth of 1.5 m above the bottom from a small boat.

The sampling mooring buoy was originally designed to collect samples with a fixed barge that was anchored by spuds to the bottom. This stationary platform would allow for collection of T_{-1} samples, samples during the pulling event, and samples at approximately 5 minutes after the pulling event (T_2). However, due to difficulties deploying the barge spuds, all pilings pulled during monitoring events were pulled using a "live boat" without spuds. This meant that the barge was not on station for a fixed period of time and the barge was moved to the next pulling site almost immediately following the pulling event. For this reason, it was not always possible to collect the T_{-1} or T_2 samples. In addition, the control sample was originally designed to be collected from a sampling port on a fixed mooring up current of the piling being pulled. This would allow the support boat to conduct transects during pulling events. Since the barge was not fixed, a control mooring buoy was not deployed and the support boat was used for control samples and, when possible conducting transects.

4.1 General Observations

With the exception of the first day of piling removal, all pilings were removed using a vibratory hammer. The tug boat, *M/V Valient* would position the work barge

alongside the piling or group of pilings being removed. The tug would generally use both stern propellers and bow thrusters to position the barge. Once on station, the vibratory hammer was placed over the head of the piling and locked into place. The vibratory hammer was generally turned on for approximately 10 to 20 seconds and was used only to loosen the piling from the bedded sediment, not to lift the piling. The vibratory hammer was then detached from the piling and the piling directly pulled from the sediment. In some cases, the piling was moved from side to side to further break the bond between the sediment and the piling.

Conditions were generally calm during piling removal, although there were periods with a fresh breeze and some chop. Water clarity was generally good during the piling removal process. Depending upon the amount of maneuvering required by the *M/V Valient*, a substantial suspended-sediment plume was created with the arrival of the tug boat. There was little evidence of sediment suspension or creosote as a result of the vibratory hammer being turned on. As the piling was extracted from the sediment, a visible plume of sediment was generally visible, approximately 3 to 5 meters in diameter. This was accompanied with varying amounts of surface slick. For some pilings, large amounts of creosote and gas bubbles would rise to the surface, covering the boomed area with a slick. Once the piling was removed, the tug would reposition the barge. A very large sediment plume was created during this process, and easily overwhelmed any visible plume created by the piling removal. It was noted on July 27th, that the visible sediment plume from the piling pulling activities, primarily the tug movement, extended from the "50 group" to the mouth of the Jimmycomelately Creek (Figure 4.1). TSS measurements and visual observations indicate that the sediment plume did not extend further east than the mouth of Jimmycomelately Creek. Described piling activities are shown in Figure 4.2.

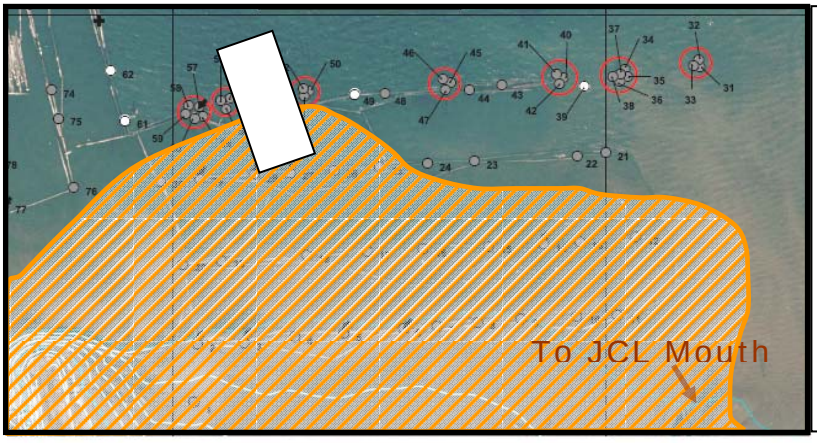


Figure 4.1. Approximate area with elevated turbidity during the removal of the "50 group" of pilings. White rectangle represents the barge.

Figure 4.2. Piling removal activities: (a) sediment plumes associated with tug boat movements; (b) tug boat prop wash (c) creosote sheen following piling removal.

4.2 PAH Concentrations

PAHs were measured in water samples collected from three depths near the piling that was being removed (Bottom, Mid, and Surface), as well as from a control location that was upwind and upcurrent of the piling and outside the influence of the tug boat and barge. When it was not possible to set the sampling buoys, grab samples were collected with a bottle sampler that allowed instantaneous sample collection. Samples were collected at four different time intervals:

T_{-1}: collected approximately 5 minutes prior to piling removal. This time period varied somewhat depending upon the amount of time between the barges arrival on site and the beginning of piling removal;

T_0: collected when the vibratory hammer was turned on;

T_1: collected when the piling was pulled from the bottom;

T_2: collected approximately 5 minutes following piling removal. This sample was only possible when the barge did not immediately leave the station.

Total PAHs were measured for all samples using ELISA detection. A subset of test samples, as well as each of the control samples, was also analyzed using GC/MS. For those samples that were analyzed with both analytical methods, the PAH concentrations were similar, with the exception of sample 97 T_2 (Table 4.1).

PAH concentrations in the ambient samples were generally low, with total PAHs ranging from 1.6 to 16.6 µg/L. Samples at T_{-1} from each of the depths at the piling being removed were generally similar to ambient levels. However, the T_{-1} Bottom sample at removal events 26 and "80 group" were 26.1 and 35.9 µg/L. In each case the T-1 sample for the ambient sample was <5 µg/L. These PAH concentrations may be the result of other removals in the area or small amounts of sediment or creosote in the sample.

In six of the ten events monitored, PAH concentrations did not change when the vibratory hammer was activated (T_0). In four pulling events, PAH concentrations increased with hammer activation within 50 cm of the bottom and in three events elevations, relative to T_{-1}, occurred at 1.5 m from the bottom. With the exception of Piling 18, PAH concentrations increased during the extraction of the piling from the bottom (T_1). The highest concentrations that were observed ranged from 100 to 200 µg/L. Elevated concentrations were observed in samples collected at each of the sampled depths, with the highest concentrations generally occurring near the bottom. The T2 samples indicated that in many cases, the PAH concentrations did not decrease within five minutes. Longer time intervals were not possible due to the movement of the barge and sampling equipment soon after piling removal.

Table 4.1 PAH Concentrations in Water Column Samples

Sampling Event (Piling)	Sample Location	Total PAHs (µg/L)			
		T_{-1}	T_0	T_1	T_2
Piling 80	Ambient	3.8	--	1.8	4.2
	Bottom	35.9	77.4	87.1	85.5
	Mid	0	26.1	24.4 (18[a])	36.1
	Surface	3.1	12.7	5	52.9
Piling 81	Bottom	--	--	131.9	--
Dolphin 65	Ambient	0.8	16	3.6	--
	Bottom	2.6	2.4	92.5	--
	Mid	0.5	0.7	3.5	--
	Surface	7.1	1.3	5.1	--
Piling 74	Ambient	--	2.6	2.7	--
	Bottom	--	11.4	109.1	--
	Mid	--	--	122.9	--
Piling 96	Ambient	16.6	--	--	--
	Bottom	--	31.7	21.5 (20.8[a])	69.3
	Mid	7.8	29.5	35.7	128.1
	Surface	11.3	7.5	23.5	13.6
Piling 97	Bottom	--	64.6	218 (21.4 [a])	40.1
Control 1 (7/27)	Mid	2.0 U[a]			
Control 2 (7/27)	Mid	2.0 U[a]			
Dolphin 58	Ambient	9.1	1.5	0.6	--
	Bottom	7.9	6.0	149	--
	Mid	5.4	3.7	99.7	--
	Surface	4.3	3.4	42	--
Dolphin 50	Ambient	2.1	0.5	3.3	1.8
	Bottom	6.9	39.7	24.9	134.7
	Mid	13.2	5.2	42.3	27
	Surface	7.2	24	47.8	120.4
Piling 26	Ambient	2.5	1.7	1.6	--
	Bottom	26.1	26.4 (21.6 [a])	91.2	--
	Mid	4.1	2.2	59.7	54.5
	Surface	6.7	2.3	42.3	--
Piling 18	Ambient	2.4	--	6.3	--
	Bottom	8.4	32.7	4.0	--
	Mid	5.2	60.1	2.9	--
	Surface	5.6	18.1	13	--
Piling 17	Ambient	11.5	--	--	--
	Bottom	--	4.0	199.9	42.2
	Mid	--	2.9	49.3	77.5
	Surface	--	13.0	133.4	18.3
Control 1 (7/28)	0.3 J[a]				
Control 2 (7/28)	<2.0 U[a]				

[a] Concentration measured with GC/MS

The PAHs observed in the water samples were dominated with mid-weight PAHs, including acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, and pyrene (Table 4.2).

The two control sites were sampled at the end of each sampling day to allow for the transport of material from the log yard to other portions of south Sequim Bay. With the exception of naphthalene in C1 7/27, PAHs were not detected in any of the control sites, indicating that on June 27th and 28th, piling removal activities did not appear to result in measurable PAHs in the water column in central or eastern South Sequim Bay.

There are no State ambient water quality criteria for total PAHs in water; however, NOAA has published guidelines for PAHs as a class of chemicals (NOAA 2003). For nearly all PAHs, the Lowest Observable Effects Level (LOEL) is 300 µg/L, including total PAHs. The LOEL represents the lowest concentration of PAHs for which observable toxic effects have been previously observed. This value is above all measured values observed during the pile pulling events.

Table 4.2 PAH Constituents in Selected Water Samples

Analyte	PAH Concentrations (µg/L)								
	C1 7/27	C2 7/27	C1 7/28	C2 7/28	80 T_1	96 T_1	97 T_1	97 T_2	26 T_1
Naphthalene	**0.2**	0.1 U	0.1 U	0.1 U	**0.13**	0.11	0.11	0.10	**0.92**
2 Methylnaphthalene	0.1 U	0.1 U	0.1 U	0.1 U	0.11 U	0.11	0.11	**0.41**	**0.98**
Acenaphythylene	0.1 U	0.1 U	0.1 U	0.1 U	0.11 U	**0.11**	**0.14**	**0.12**	0.10
Acenaphthene	0.1 U	0.1 U	0.1 U	0.1 U	**1.9**	**4.8**	**4.8**	**7.9**	**1.4**
Fluorene	0.1 U	0.1 U	0.1 U	0.1 U	**2.0**	**0.85**	**0.25**	**6.6**	**1.4**
Phenanthrene	0.1 U	0.1 U	0.1 U	0.1 U	**5.6**	**0.86**	**1.5**	**8.6**	**5.8**
Anthracene	0.1 U	0.1 U	0.1 U	0.1 U	**0.46**	**0.33**	**0.35**	**1.6**	**0.64**
Fluoranthene	0.1 U	0.1 U	0.1 U	0.1 U	**3.2**	**7.9**	**8.5**	**8.3**	**4.3**
Pyrene	0.1 U	0.1 U	0.1 U	0.1 U	**1.9**	**4.0**	**3.4**	**4.8**	**3.1**
Benzo(a)anthracene	0.1 U	0.1 U	0.1 U	0.1 U	**0.23**	**0.47**	**0.66**	**0.65**	**0.5**
Chrysene	0.1 U	0.1 U	0.1 U	0.1 U	**0.38**	**0.85**	**1**	**0.66**	**1.1**
Benzo(b)fluoranthene	0.1 U	0.1 U	0.1 U	0.1 U	0.11 U	**0.16**	**0.22**	**0.13**	**0.32**
Benzo(k)fluoranthene	0.1 U	0.1 U	0.1 U	0.1 U	0.11 U	**0.14**	**0.17**	**0.11**	**0.26**
Benzo(a)pyrene	0.1 U	0.1 U	0.1 U	0.1 U	0.11 U	0.11	**0.12**	0.10	**0.20**
Indeno(1,2,3-cd)pyrene	0.1 U	0.1 U	0.1 U	0.1 U	0.11 U	0.11	0.11	0.10	0.10
Denbenz (ah)anthrancene	0.1 U	0.1 U	0.1 U	0.1 U	0.11 U	0.11	0.11	0.10	0.10
Benzo(g,h,i)perylene	0.1 U	0.1 U	0.1 U	0.1 U	0.11 U	0.11	0.11	0.10	0.10
Dibenzofuran	0.1 U	0.1 U	0.1 U	0.1 U	**1.5**	**1.8**	**0.56**	**5.6**	**0.89**
Total PAHs	**0.95**	**0.9**	**0.9**	**0.9**	**18**	**20.8**	**21.4**	**40.1**	**21.6**

U: Undetected – actual concentration is at or below the reported value.

4.3 Suspended Sediment

Suspended solids (TSS) were monitored using OBS sensors and a YSI turbidity meter. TSS readings were recorded using sensors attached to mooring buoys approximately 1 meter (OBS 1) and 15 meters (OBS 2) of the piling being removed. A control OBS sensor was deployed from the support vessel at a location that was upcurrent and out of the direct influence of the tug boat. The OBS sensors measured suspended solids in mg/L and the YSI meter measured turbidity in nephelometric turbidity units (NTU). Based on calibrations, the relationship between these TSS and NTUs was approximately 1:1.

TSS data were analyzed in three ways. TSS values during pulling events were evaluated graphically to observe the general trends and to better understand what sediment movement occurred with specific events. TSS for specific time intervals were also analyzed to determine quantitative changes in water quality during certain pulling events. It is important to note that the OBS sensors evaluate very short distances and are therefore prone to short events that may result in apparent spike in TSS (such as a large particle, algae or fish moving past the optical sensor). Quantitative changes were based on a moving average of three points to minimize the impact of spike in TSS. In addition to these fixed readings, transects were performed during five pulling events.

The fixed OBS sensor readings showed several patterns that appeared to be repeated in many of the pulling events (Figures 4.3 through 4.6). In each case, the probes were placed prior to any pulling acitivities, establishing TSS background levels. In addition, an OBS sensor was deployed at a control location out of the influence of the pulling acitivities. Background levels were approximately 10 mg/L and did not appear to increase during the day.

TSS concentrations were approximately 10 mg/L prior to the arrival of the tug. The prop wash associated with the tug maneuvering resulted in increased turbidity, with TSS concentrations increasing to over 10-times background. The period of time in which the TSS concentrations remain elevated was generally less than 5 minutes. The increased turbidity from the prop wash was not limited to discrete areas and was generally observed on both OBS sensors.

Following the arrival of the tug, the TSS concentrations returned to baseline. The activation of the vibratory hammer resulted in small increases in TSS, generally at the piling being removed (OBS 1). TSS increases associated with the vibratory

hammer were 5 to 10 mg/L. The removal of the piling from the sediment, the pull, resulted in an increase in turbidity. Qualitative observations from the vessel during the pulling events indicated that a sediment "plume" of 5 to 10 meters was created during the pulling events. This is reflected in the OBS readings, with increases during the extractions of 10 to 20 mg/L. This was generally observed both for OBS 1 and OBS 2. It is important to note that for some pulling events, there is no clear increase in TSS that is associated with the vibratory hammer or extraction. Following extraction, the signal for the tug prop wash was sometimes observed. This again resulted in TSS concentrations exceeding 100 mg/L.

Quantitative comparisons of TSS concentrations were made for each monitored extraction (Table 4.3). Seven time intervals were evaluated for the control station, the OBS-1 station within 1 meter of the piling, and when possible, the OBS-2 station. Time intervals that were evaluated were:

- prior to the arrival of the tug
- the arrival of the tug and barge
- the T_{-1}, T_0, T_1, and T_2 time intervals that coincided with the PAH sampling,
- and the tug exit.

Because TSS measurements are subject to single spikes that are a result of interferences, rather than true increases in suspended solids, a mean of three values was used for each individual sampling event.

Mean TSS concentrations prior to the arrival of the tug generally ranged from 6 to 12 mg/L and were generally consistent between the control station and the OBS 1 and OBS 2 sensors. The only exceptions were at stations where piling removals were conducted in the immediate vicinity prior to the arrival of the tug (Pilings 97 and 17). In the case of Piling 17, the baseline TSS concentrations were elevated to approximately 20 mg/L for the general area, including the control station.

Upon the arrival of the tug and barge, TSS concentrations increased 2 to 20 times, with mean TSS concentrations ranging from 15 to 162 mg/L. The increase in suspended sediment concentrations was broadly distributed in the area of the piling being removed, with both OBS sensors showing increases in TSS. In most cases the TSS concentrations returned to background prior to piling removal, generally within 5 minutes. This is presumably due to a combination of the heavier sediment falling out and the lighter fractions moving out of the area. For pulling events 50 and 26, the TSS concentrations did not return to background prior to pulling. This may have been due to continued maneuvering of the tug, especially during windy conditions.

Mean TSS concentrations increased slightly with the activation of the vibratory hammer, generally within four times that of the T_{-1} sample. Mean TSS concentrations ranged from 13 to 43 mg/L. The influence of the vibratory hammer appeared to be localized, with the mean TSS concentrations lower at the OBS-2 sensor than those of the OBS-1 sensor.

During the pulling event, suspended sediment was sometimes visible in the water column, with a plume of sediment 3 to 5 meters in diameter. This was reflected in the TSS measurements, with mean TSS concentrations ranging from 20 to 82.9 mg/L at the OBS-1 and OBS-2 sensors. TSS concentrations were similar at the two stations during the pull indicating that the suspended sediment extended at least 15 to 20 ft. away from the actual pulling event. Mean TSS concentrations generally decreased following the pull, with TSS concentrations at T_2 ranging from lightly lower at the OBS-2 sensor, ranging from 16 to 55 mg/L. This time interval was often unavailable since the tug moved from the monitored station soon after the piling cleared the water's surface.

TSS concentrations increased as the tug moved the barge from the monitored station. This did not necessarily occur at every station and often this data was unavailable because the sensors would be pulled to protect them from damage from the barge or tug propellers. Mean TSS concentrations during the exit ranged from 21 to 134 mg/L.

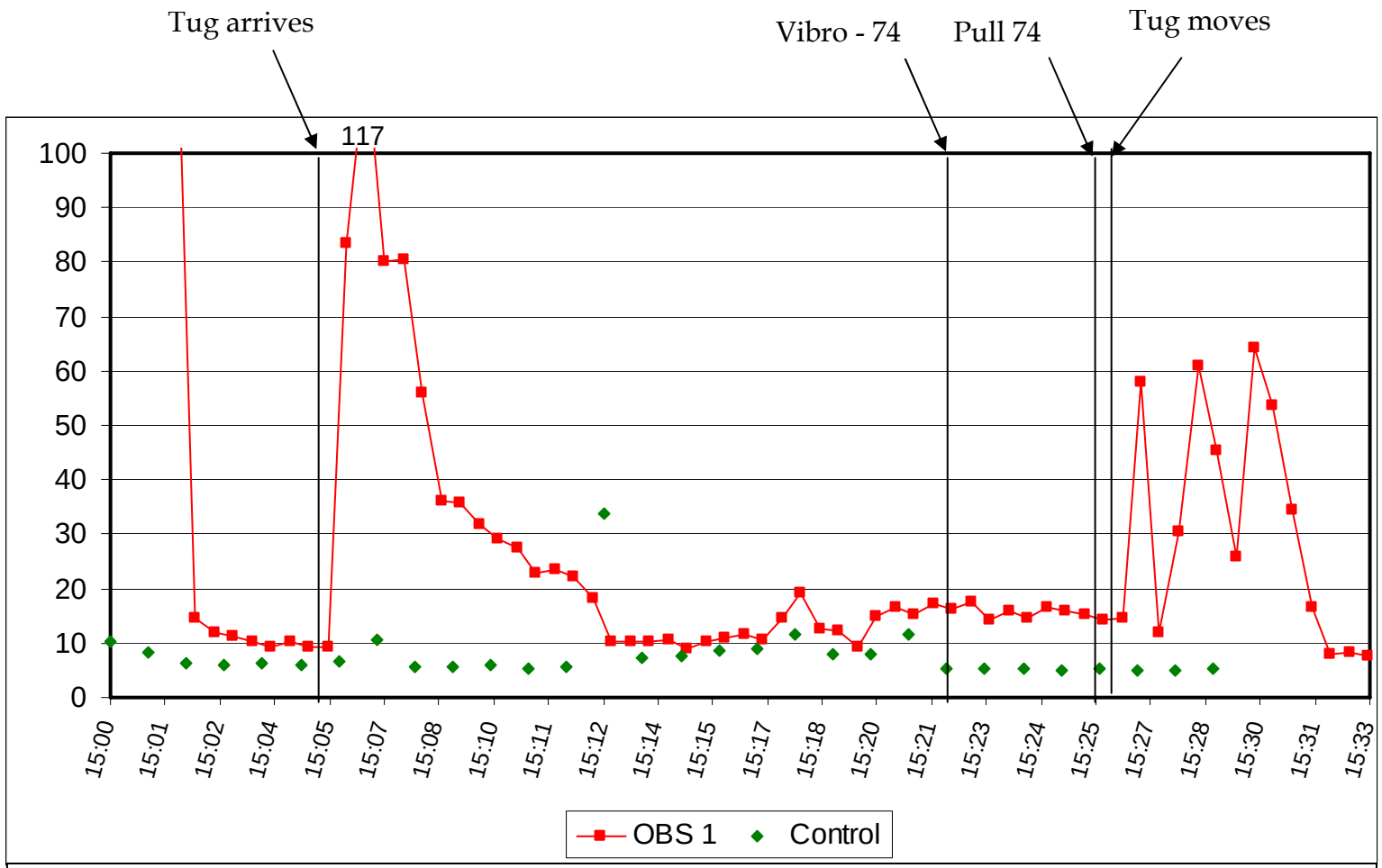


Figure 4.3. TSS profiles for OBS 1 and Control locations during the removal of Piling 74.

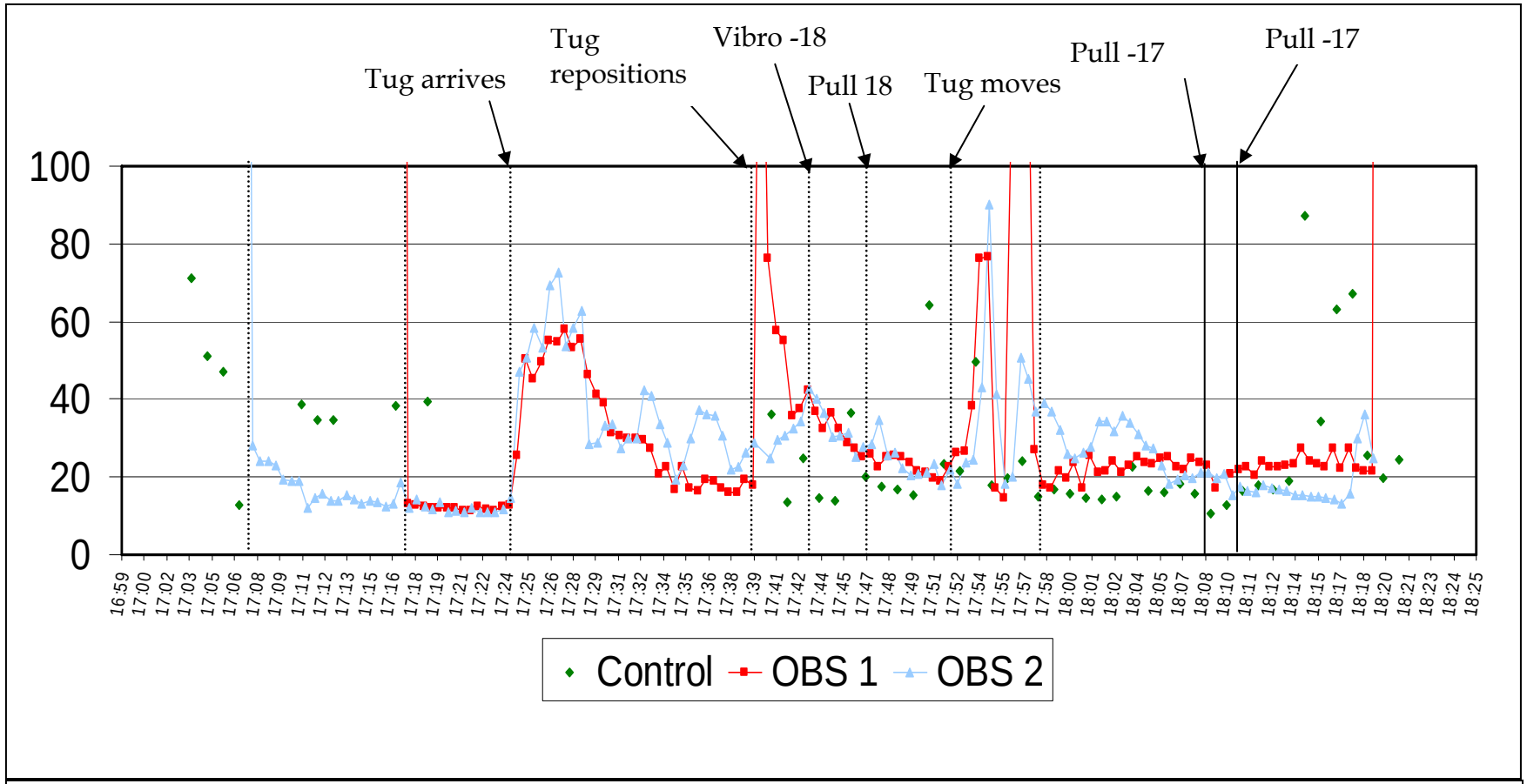


Figure 4.4. TSS profiles for OBS-1, OBS-2 and Control locations during the removal of Pilings 18 and 17.

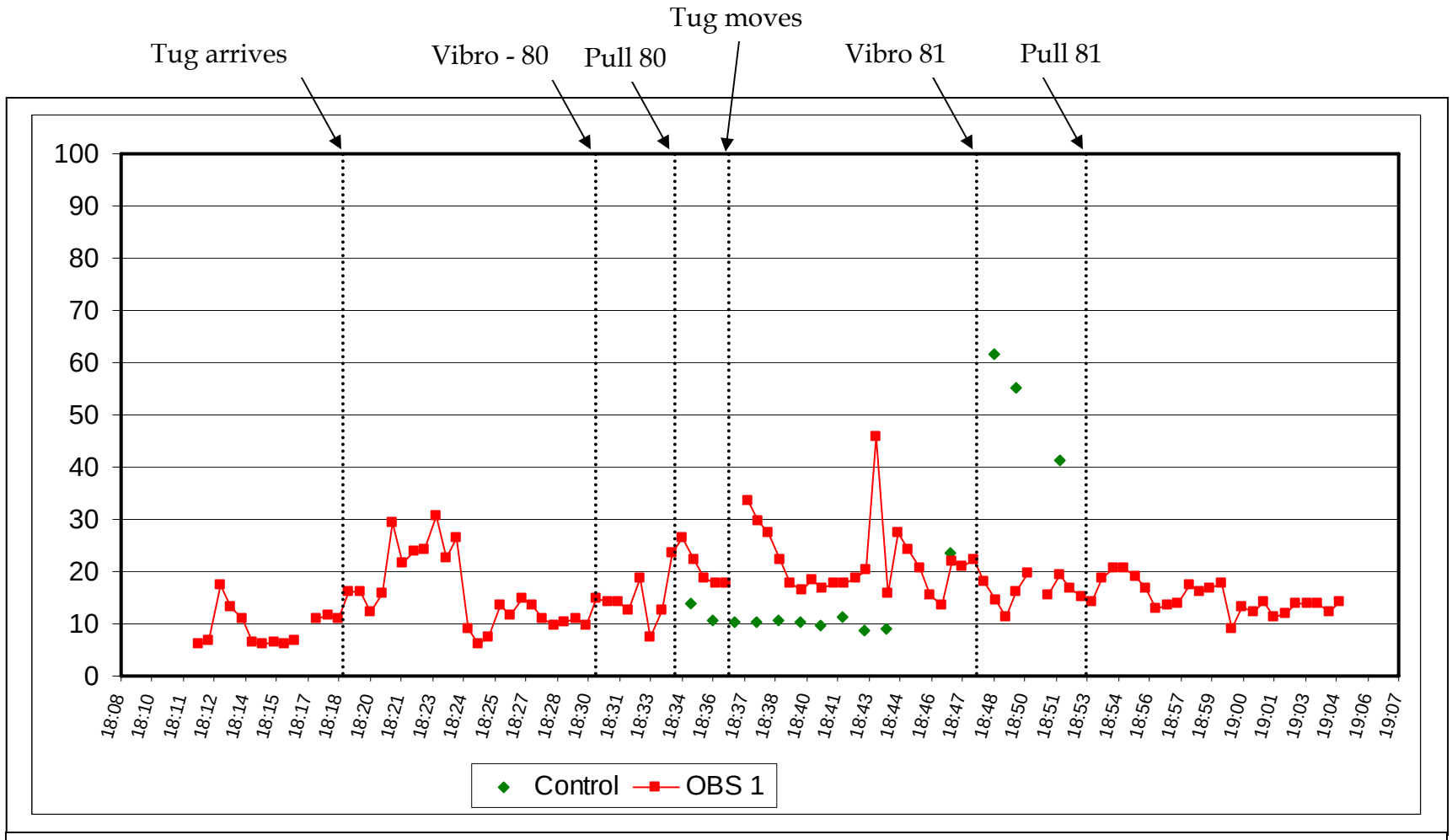


Figure 4.5. TSS profiles for OBS 1 and Control locations during the removal of Pilings 80 and 81.

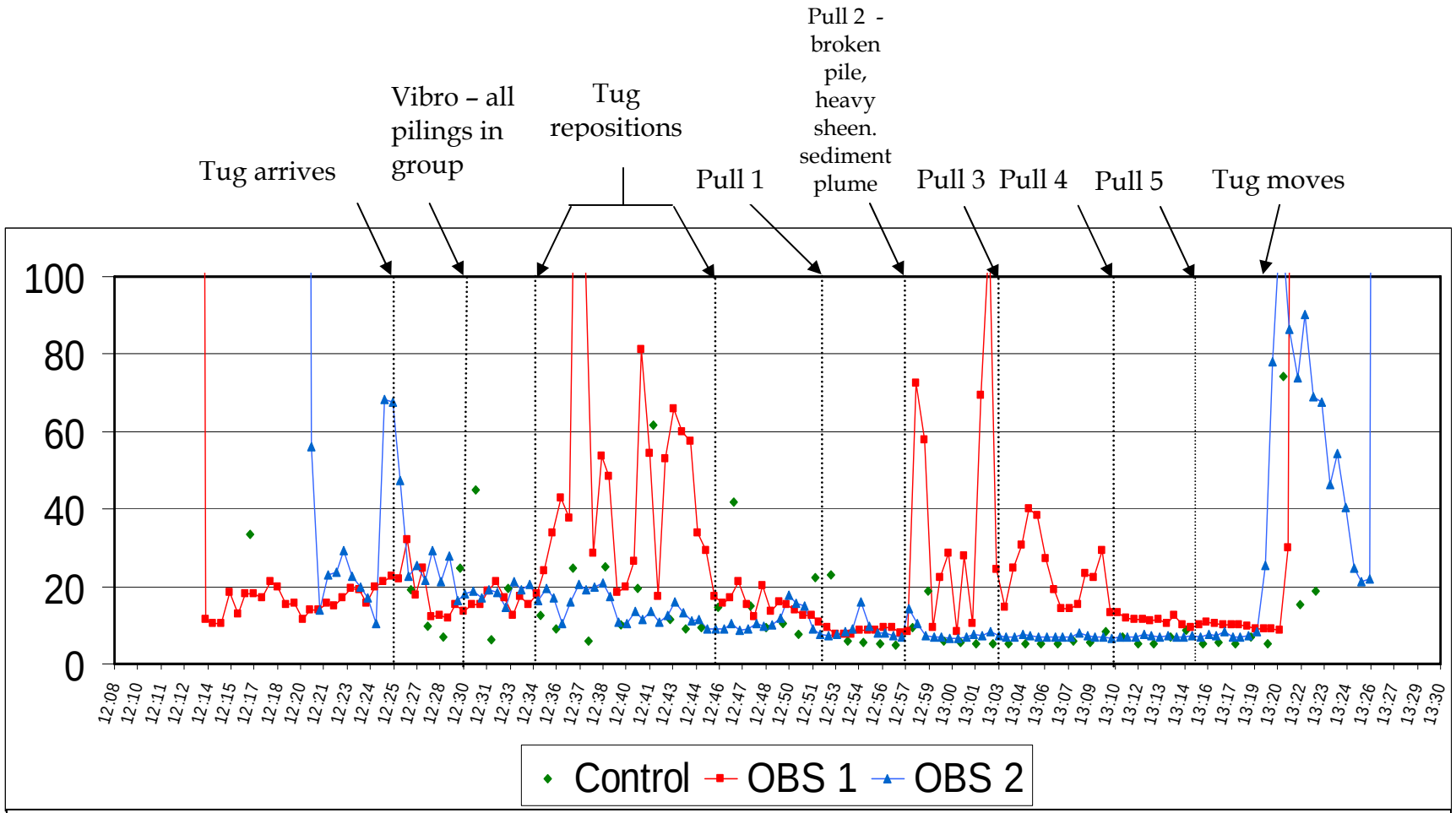


Figure 4.6. TSS profiles for OBS-1, OBS-2, and Control locations during the removal of 58-Group.

Table 4.3 Mean TSS Concentrations (mg/L) Observed during Piling Removal

Sampling Event		Prior to Tug	Tug Arrival	T_{-1}	T_0	T_1	T_2	Tug Exit
July 27, 20005								
93	Control	8	n/a	n/a	n/a	5	5	28
	OBS 1	8	n/a	8	43	24	10	n/a
80	Control	n/a	n/a	10	n/a	12	n/a	n/a
	OBS 1	11	29	15	31	22	n/a	n/a
74	Control	6	11	8	5	5	n/a	6
	OBS 1	10	117	10	18	44	n/a	43
65	Control	6	5	5	6	6	n/a	
	OBS 1	8	48	14	27	36	13	102[@]
96	Control	7	9	9	13	7	n/a	n/a
	OBS 1	11	15	16	18	50	n/a	150
97	Control	8	7	7	20	n/a	n/a	n/a
	OBS 1	39	150	17	40	37	n/a	n/a
July 27, 20005								
58	Control	n/a	n/a	15	35[p]	8	n/a	5.62
	OBS 1	n/a	n/a	16	30	65/68/25/10/9	n/a	n/a
	OBS 2	n/a	n/a	15	10	n/a	n/a	n/a
50	Control	8	n/a	7	8		n/a	32
	OBS 1	11	90	30	30	20	n/a	100
	OBS 2	9	162	82	22	12	n/a	21
26	Control	7	38	7	8	13	19	26
	OBS 1	12	92	100	134	50.3	43	134
	OBS 2	10	14	119	34	82.9	55	96
18	Control	n/a	n/a	17	15	20	18	18
	OBS 1	11	54	26	21	76	24	155
	OBS 2	6	53	20	13	58	23	33
17	Control	17	18	15	11	13	16	46
	OBS 1	22	155	21	18	23	22	90
	OBS 2	19	33	18	12	9	18	30

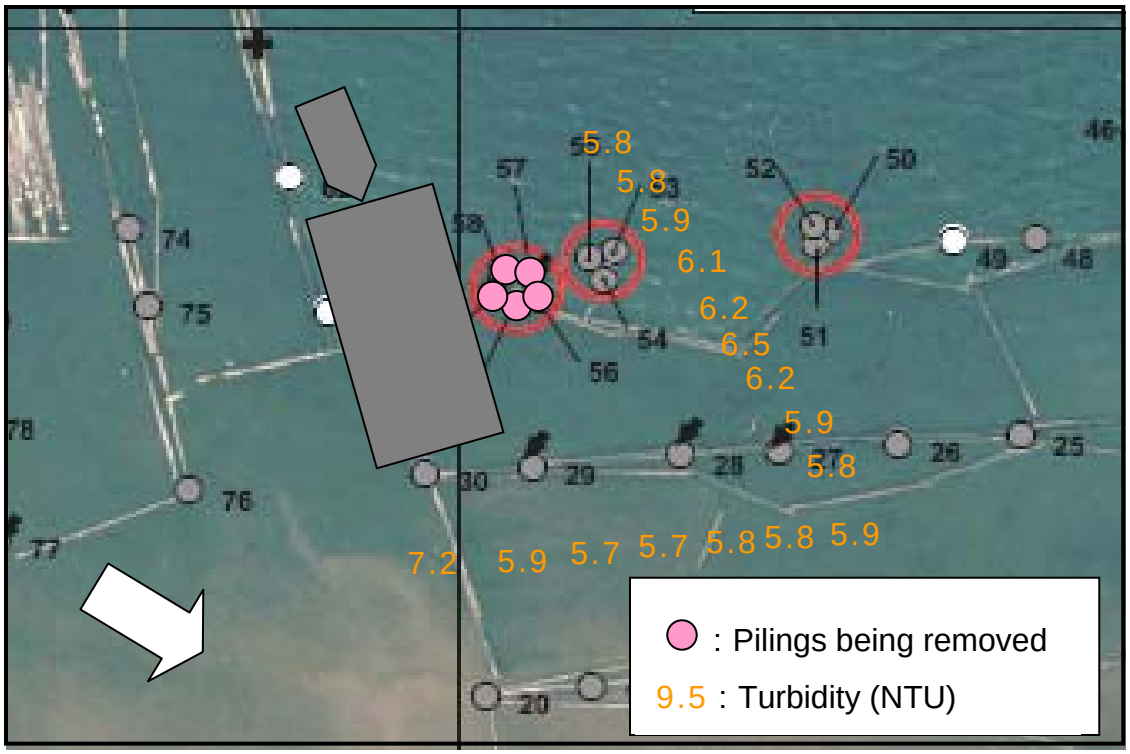
Table 4.3 Continued

Sampling Event		TSS (mg/L)						
Control Site 1	YSI (NTU)	6.0						
Control Site 2	YSI (NTU)	7.6						
Control Site 1	YSI (NTU)	6.4						
	TSS (mg/L)	6.2						
Control Site 1	YSI (NTU)	7.6						
	TSS (mg/L)	9.4						

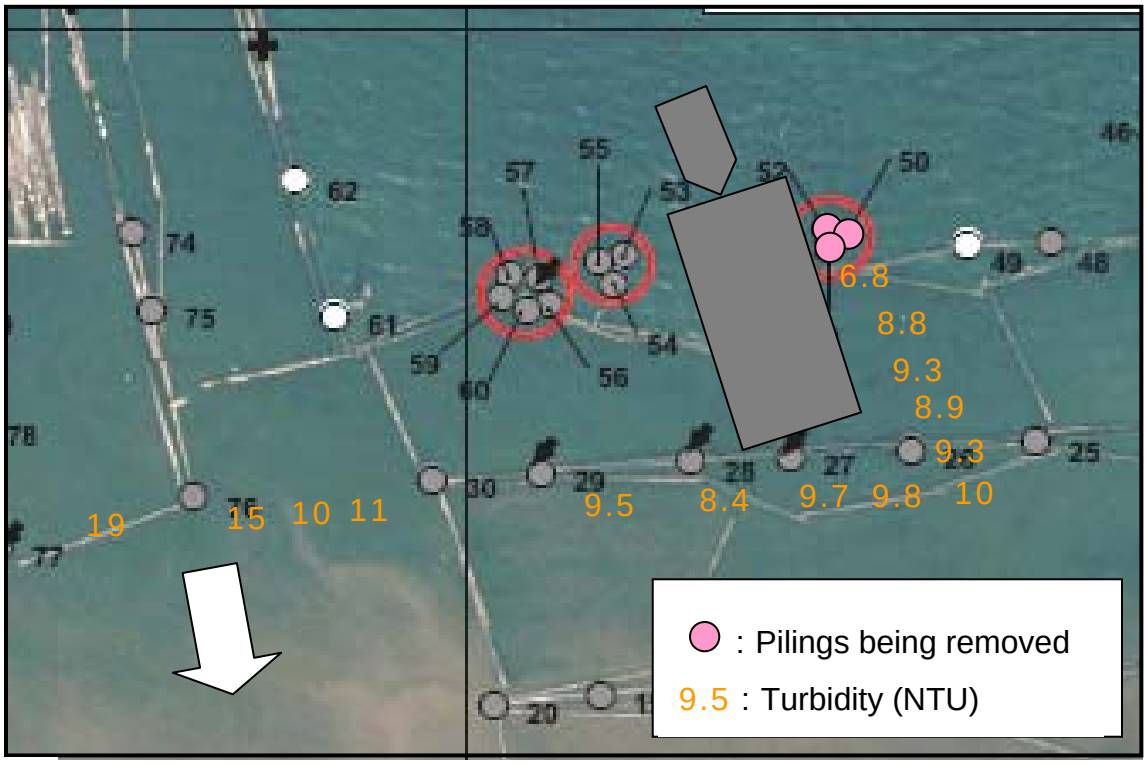
@ Tug repositioning during pull

The fixed OBS stations were able to provide an indication of sediment suspension in areas close to the removal activities. In order to evaluate the changes in TSS across the area during piling removal, transects were conducted in the former log yard during three separate removal events and across the south end of Sequim Bay after an 8-hour period of piling removal. Turbidity was measured using the YSI turbidity meter at a depth of approximately 1-m below the surface. In the log yard, transects were conducted during the removal of dolphins "58-group" and "50-group" and piling 74, (data presented in Figures 4.7 and 4.8; Appendix F). In Sequim Bay, a transect from east to west was conducted across the south end of the Bay after an extended period of piling removal in order to evaluate the potential impact of piling removal activities to the larger area of south Sequim Bay (Figure 4.9).

Background turbidity in Sequim Bay was approximately 5 to 10 NTUs at the time of the monitoring activities. During removal of the group of pilings comprising "dolphin 58" there was no observable increase in turbidity at distances 20 to 50 meters from the removal activities. There was some increase in turbidity observed during the removal of "dolphin 50"; however, increases in turbidity were within 5 NTUs of background downstream of the piling removal (based on current and wind-driven water movement). Turbidity of 10 to 20 NTUs were observed in areas further removed from the removal activities. It is unclear whether these were from previous activities or from tug boat and barge movement; however, they did not appear to be associated with the piling extraction activities. Increases in turbidity were observed during the removal of piling 74. These were limited to those areas within approximately 30 meters of the pilings. It is difficult to discern whether the turbidity was from the piling removal itself or from the tug boat movements. Based on the south Sequim Bay transect, there was no significant increases (>5 NTU above background) in areas beyond the former log yard.



a.



b.

Figure 4.7. Transects conducted during the removal of (a) Dolphins 58 and (b) 50. Transects conducted during the vibratory hammer and piling extraction. Values in orange represent turbidity readings (NTU). White arrow indicated dominant water movement. Grey polygons represent position of tug and barge.

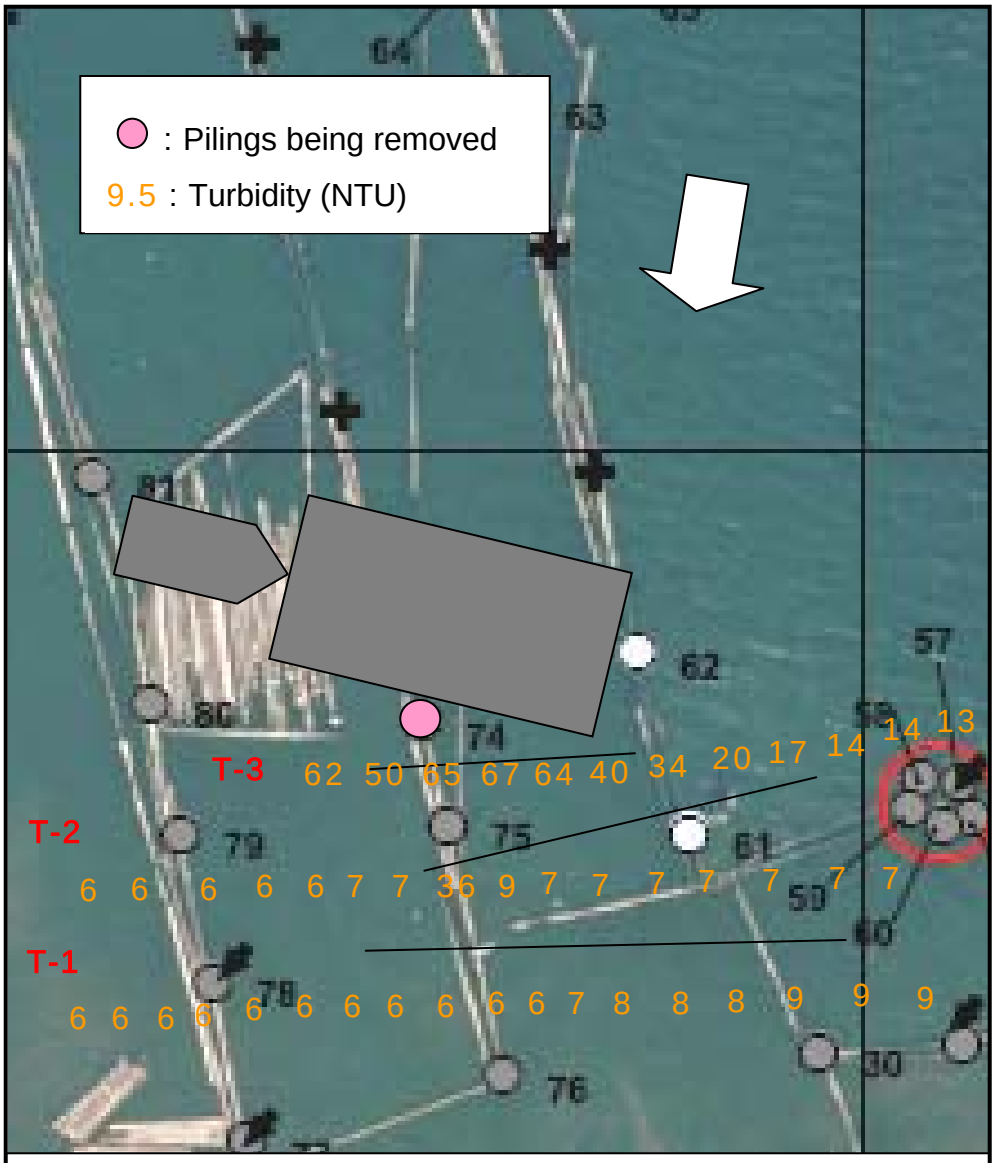


Figure 4.8. Transects recorded during the extraction of piling 74. Transect 1 and 2 (T-1 and T-2) recorded during vibratory hammer activation and Transect 3 (T-3) recorded during piling removal. Orange values indicate measured turbidity (NTU). White arrow indicates direction of water movement. Grey polygons represent position of tug and barge

Figure 4.9. Turbidity reading recorded along a transect across the south end of Sequim Bay after approximately 8 hours of piling removal activity. Orange values indicate turbidity (NTU). White arrow indicates direction of water movement. Grey rectangle represents position of barge at the time of the transect.

5.0 Results of Post-Removal Sediment and Tissue Sampling

Following piling removal, sediment was sampled to evaluate the potential for redistribution of PAHs in the former log yard and vicinity. Sediment PAH concentrations were also used to estimate tissue concentrations for those areas not available for sampling, either because of the absence of target clam species or because of depth. In addition, tissue samples were collected from the former log yard and vicinity to directly estimate human health risk from the harvest and consumption of intertidal clams from the area. This section presents the result of the sediment and tissue analysis. Results of the post-removal HHRA are presented in Section 6.

5.1 PAH in Post-Removal Sediments

In order the evaluate the potential for redistribution of creosote-contaminated sediment during piling removal, surficial sediment was collected from 50 randomly selected stations in the log yard, the surrounding area, and near the mouth of the Jimmycomelately Creek (Figure 5.1). In addition, samples were collected from the two control stations, C1 and C2. Surface samples were collected with a modified Ponar grab that captured the upper 5 cm of sediment. Sediment samples were collected on September 7, 2005, approximately five weeks after piling removal. Station locations are listed in Table 5.1.

All log yard sediment samples were analyzed for total PAHs using ELISA as a screen for PAHs. Total PAHs were detected in each of the stations evaluated with ELISA, including the control stations (Table 5.1). Total PAHs were detected at very low concentrations, with the highest total PAH concentration of 33.3 µg/kg dw.

Analysis of 18 individual PAHs and total organic carbon were also evaluated in a subset of 8 samples from the log yard and the two control stations (Table 5.2). Total PAH) in the surface samples ranged from 57.4 to 576 µg/kg dw. The ELISA chemistry results were adjusted to the GC/MS results using an 11:1 ratio ($R^2 = 0.98$) developed with the matching data sets. The adjusted concentrations were then used to evaluate the PAH concentrations across the log yard. The results of the GC/MS analysis were used in the post-removal risk assessment (Section 6.4).

In general, the post-removal concentrations of total PAHs in the former log yard and surrounding area were very low, with total PAHs ranging from 0 to 500 µg/kg dw (Table 5.1). In contrast, concentrations of PAHs in pre-removal sediments collected from the immediate vicinity of pilings prior to removal ranged from 677 to over 189,868 µg/kg dw. As in the pre-removal sediment samples, the distribution of PAHs was dominated by mid-range PAHs, such as fluoranthene, pyrene, benzo(a)anthracene, and chrysene. The carcinogen, benzo(a)pyrene, was observed at concentrations ranging from <6.3 to 9.0 µg/kg dw. Samples collected prior to

piling removal ranged from 20.2 to 1,034 µg/kg dw. Despite the detection of PAHs in the water column during piling removal and mobilization of sediments from the log yard, it did not appear to result in a spreading of the higher PAH concentrations observed in the immediate vicinity of the pilings.

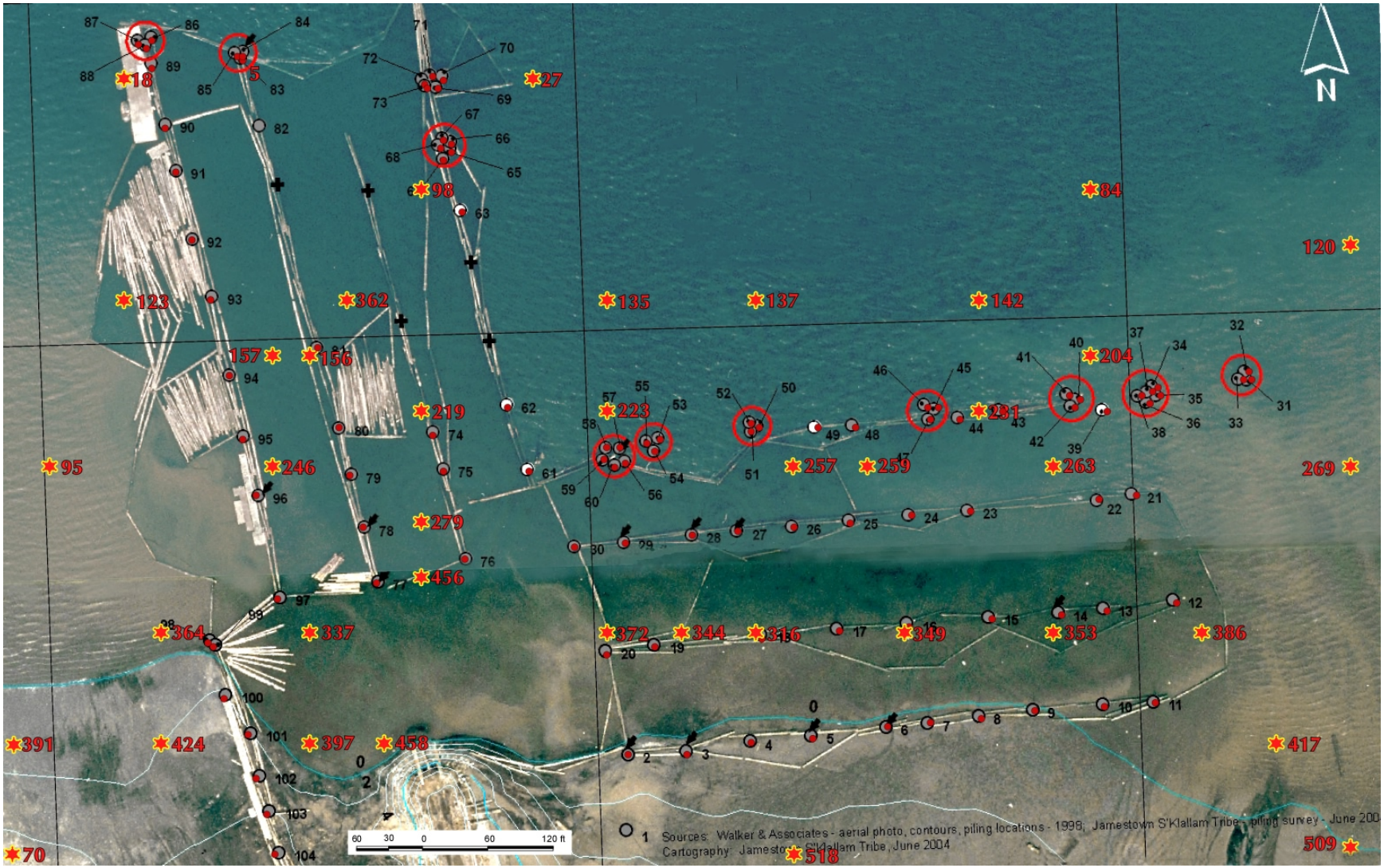


Figure 5.1. Locations of post-removal, surface sediment sampling stations within the former log yard.

Table 5.1 Post-removal Sediment PAH Concentrations

Station	Latitude (ºN)	Longitude(ºW)	Total PAH (µg/kg)	Adjusted PAH (µg/kg)
C1	48 01 39.0	123 00 17.0	2.93	0
C2	48 01 35.0	122 59 55.2	3.80	0
5	48 01 43.0	123 00 39.0	21.17	303
18	48 01 43.0	123 00 40.5	24.99	366
25	NA	NA	32.08	88
27	48 01 43.0	123 00 35.0	7.94	304
70	48 01 36.0	123 00 42.0	21.23	114
72	48 01 35.0	123 00 42.0	9.55	4
84	48 01 42.0	123 00 27.5	2.79	136
95	48 01 39.5	123 00 41.5	10.88	133
98	48 01 42.0	123 00 36.5	10.69	0
120	48 01 41.5	123 00 24.0	1.36	80
123	48 01 41.0	123 00 40.5	7.49	61
135	48 01 41.0	123 00 34.0	6.32	303
137	48 01 41.0	123 00 32.0	21.17	116
142	48 01 41.0	123 00 29.0	9.66	149
156	48 01 40.5	123 00 38.0	11.72	35
157	48 01 40.5	123 00 38.5	4.71	0
204	48 01 40.5	123 00 27.5	1.84	251
219	48 01 40.0	123 00 36.5	17.93	72
223	48 01 40.0	123 00 34.0	6.94	122
231	48 01 40.0	123 00 29.0	10.05	121
231	48 01 40.0	123 00 29.5	9.99	476
246	48 01 39.5	123 00 38.5	31.79	363
257	48 01 39.5	123 00 31.5	24.84	148
259	48 01 39.5	123 00 30.5	11.61	0
263	48 01 39.5	123 00 28.0	2.31	303

Table 5.1 Continued.

Station	Latitude (°N)	Longitude (°W)	Total PAHs	Adjusted PAHs
266	48 01 26.5	123 00 39.5	5.49	48
269	48 01 39.5	123 00 24.0	22.54	326
279	48 01 39.0	123 00 36.5	15.76	215
316	48 01 38.0	123 00 32.0	7.04	73
353	48 01 38.0	123 00 28.0	22.16	320
337	48 01 38.0	123 00 38.0	33.25	500
344	48 01 38.0	123 00 33.0	28.49	423
349	48 01 38.0	123 00 30.0	10.08	123
362	48 01 41.0	123 00 37.5	6.28	61
364	48 01 38.0	123 00 40.0	12.32	159
372	48 01 38.0	123 00 34.0	16.76	232
386	48 01 38.0	123 00 26.0	29.07	432
391	48 01 37.0	123 00 42.0	3.68	18
397	48 01 37.0	123 00 38.0	19.39	274
417	48 01 37.0	123 00 25.0	11.58	147
424	48 01 37.0	123 00 40.0	15.95	218
429	48 01.569	123 00.558	13.82	184
446	48 01 26.0	123 00 37.0	6.80	69
456	48 01 37.0	123 00 38.0	21.79	313
456	48 01 38.5	123 00 36.5	21.60	310
458	48 01 37.0	123 00 37.0	16.53	228
Shallow Beach	NA	NA	11.52	146
509	48 01 36.0	123 00 24.0	8.11	91
518	48 01 36.0	123 00 37.0	12.78	167
532	48 01 35.0	123 00 30.0	3.27	12
JCL mouth	48 01.547	123 00.479	13.10	172

Table 5.2 Concentrations of Individual PAHs from Post-Removal Surficial Sediments

Analyte	Station									
	532 alt	372	337	518 alt	316	C1	C2	353	417	509
TOC	**0.53**	**4.25**	**3.11**	**1.29**	**0.923**	**0.48**	**0.93**	**1.00**	**0.80**	**2.03**
Naphthalene	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
2 Methylnaphthalene	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Acenaphythylene	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Acenaphthene	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Fluorene	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Phenanthrene	6.5 U	**9.6**	**30**	6.3 U	**61**	6.4 U	6.5 U	**12**	**18**	**27**
Anthracene	6.5 U	6.4 U	**9.1**	6.3 U	**6.5**	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Fluoranthene	**10**	**59**	**230**	**16**	**95**	6.4 U	6.5 U	**50**	**62**	**43**
Pyrene	6.5 U	**59**	**150**	**7.6**	**48**	6.4 U	6.5 U	**37**	**30**	**19**
Benzo(a)anthracene	6.5 U	**18**	**26**	6.3 U	**12**	6.4 U	6.5 U	**7.9**	**20**	6.5 U
Chrysene	6.5 U	**36**	**49**	6.3 U	**18**	6.4 U	6.5 U	**12**	**39**	**8.5**
Benzo(b)fluoranthene	6.5 U	**16**	**23**	6.3 U	**9.1**	6.4 U	6.5 U	6.6 U	**17**	6.5 U
Benzo(k)fluoranthene	6.5 U	**15**	**19**	6.3 U	**7.8**	6.4 U	6.5 U	6.6 U	**17**	6.5 U
Benzo(a)pyrene	6.5 U	**7.6**	**8.4**	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	**9.0**	6.5 U
Indeno(1,2,3-cd)pyrene	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Denbenz (ah)anthrancene	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Benzo(g,h,i)perylene	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Dibenzofuran	6.5 U	6.4 U	6.5 U	6.3 U	6.5 U	6.4 U	6.5 U	6.6 U	6.4 U	6.5 U
Total PAHs	**65.3**	**252**	**574**	**74.0**	**290**	**57.6**	**58.5**	**161.8**	**244**	**143**

U: Undetected – Actual concentration at or below the reported value.

5.2 PAH Concentrations in Post-Removal Tissues

PAH and lipid concentrations for the clam tissue composites collected in control sites and within the former log yard are presented in Table 5.3 and 5.4. The achieved detection limit for all tissue samples was <13 µg/kg. PAHs were not detected in any of the clam tissues collected from Control Sites 2 or 3, however trace concentrations of fluoranthene was detected in each of the tissue replicates sampled at Control Site 1. The detected values ranged from 10 – 19 µg/kg, which is less than the target detected limit of 20 µg/kg established in the sample and analysis plan.

Within the former log yard, total detected PAH concentrations ranged from <10 µg/kg to 26 µg/kg. With the exception of phenanthrene, fluoranthene, and pyrene, detected PAHs were below detection limits (<10 µg/kg). Again, for each individual PAH measured, all except one, was below the 20 µg/kg target detection limit. The exception occurred in Station PC-6, which had a detected concentration of fluoranthene of 26 µg/kg fluoranthene. This station also had the highest total measured PAHs in tissue (58 µg/kg). Although there are some minor differences in the PAH concentrations detected among the sample locations, the measured PAHs at all stations were quite low. When compared to tissue concentrations collected prior to piling removal, the total measured PAHs were more similar to concentrations detected in tissues collected away from the pilings (0 – 30 µg/kg), than those collected at the base of the pilings (280 – 829 µg/kg).

Table 5.3 PAH concentrations detected in clam tissue collected from three control locations in South Sequim Bay

Analyte	C1-1	C1-2	C1-3	C2-1	C2-2	C2-3	C3-1	C3-2	C3-3
Lipids %	1.09	1.06	0.891	0.721	0.813	0.706	0.623	0.565	0.868
PAHs µg/kg (ww)									
2-Methylnapthalene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Naphthalene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Acenaphthene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Acenaphthylene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Anthracene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Fluorene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Phenanthrene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Benzo(a)anthracene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Chrysene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Fluoranthene	**19**	**14**	**10**	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Pyrene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Benzo(a)pyrene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Benzo(b)flouranthene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Benzo(k)flouranthene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Dibenz(a,h)anthracene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Benzo(g,h,i)perylene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Indeno(1,2,3-cd)pyrene	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Dibenzofuran	<10 U	<10 U	<10 U	<10 U	<10 U	<13 U	<10 U	<10 U	<13 U
Total PAH	**104**	**99**	**95**	**90**	**90**	**117**	**90**	**90**	**117**

U = Concentrations at or below reported value
Bold = Detected PAH concentration
Total PAH = sum of detected PAHs + ½ of the undetected values

Table 5.4 PAH concentrations detected in clam tissue collected from within the former log yard and vicinity.

Analyte	PC - 1	PC - 2	PC - 3	PC - 4	PC - 5	PC - 6	PC - 7	PC - 8	PC - 9
Lipids %	0.916	1.09	0.900	1.10	0.883	1.29	0.859	0.546	0.717
PAHs µg/kg (ww)									
Naphthalene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
2-Methylnapthalene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Acenaphthylene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Acenaphthene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Fluorene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Phenanthrene	**11**	**19**	<10 U	<10 U	<10 U	**18**	**15**	<10 U	<10 U
Anthracene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Fluoranthene	<10 U	**19**	**12**	<10 U	<10 U	**26**	**18**	<10 U	<10 U
Pyrene	<10 U	<10 U	<10 U	<10 U	<10 U	**14**	<10 U	<10 U	<10 U
Benzo(a)anthracene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Chrysene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Benzo(b)flouranthene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Benzo(k)flouranthene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Benzo(a)pyrene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Indeno(1,2,3-cd)pyrene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Dibenz(a,h)anthracene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Benzo(g,h,i)perylene	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Dibenzofuran	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U	<10 U
Total PAH	**96**	**118**	**97**	**90**	**90**	**133**	**113**	**90**	**90**

U = Concentrations at or below reported value
Bold = Detected PAH concentration
Total PAH = sum of detected PAHs + ½ of the undetected values

6.0 Results of Human Health Risk Assessment

Human health risk assessments (HHRA) were conducted prior to piling removal (*Pre-Removal*) and following removal (*Post-Removal*). This section provides an overview of the methods and assumptions that were used in the risk assessment and summarizes the results of the HHRAs. The full risk assessments, with all worksheets and uncertainties analysis, are attached in Appendixes A and B.

The objectives of the pre- and post-removal human health risk assessments were as follows:

Pre-Removal

- To estimate health risks from human exposure to creosote-related PAHs for commercial and subsistence shellfish harvest in south Sequim Bay (the former log yard and areas currently harvested by the Tribe for commercial and subsistence fisheries);

Post-Removal

- To estimate risks from human exposure to creosote-related PAHs in the sediment and shellfish for commercial and subsistence shellfish harvest following the removal of the log yard pilings.

6.1 Background

Risk assessment is a procedure that estimates incremental increases in health risk from exposure to a known or suspected contaminant by combining the following:

- estimates of environmental contaminant concentrations;
- the toxicity and carcinogenicity of contaminant(s) of concern;
- information regarding the human populations that are potentially exposed to the contaminant(s) of concern; and,
- the manner in which exposed populations will interact with those contaminant concentrations.

Where ever possible, site-specific data were used in risk calculations. However, it is unusual to have quantitative data for all aspects of the risk assessment. Assumptions were therefore necessary to complete the risk evaluations. The risk assessment used a series of numerical models to evaluate the probability of a particular effect to specific human populations. When assumptions were used in place of data, those values were typically conservative. For certain types of chemicals, for example carcinogens, the models were very conservative.

The numerical human-health risk models used in this investigation evaluated the incremental increases in a person's risk from a particular exposure, in this case

harvest and consumption of clams from the former log yard. Incremental health risks are those risks that are associated only with the contamination that is being evaluated (ie. exposure to Sequim Bay clams and sediments) and does not include other sources of contamination. Rather, the estimated incremental health risks are in addition to any background health risks that members of the local population might be exposed to. Since the models evaluate only incremental risks, they do not take into account other risk factors of an individual's lifestyle. It should be pointed out that, while the incremental risk does not take into account other risk factors of someone's lifestyle, the acceptable limits *are* based on an understanding of those other risks. The goal is to keep risks from additional exposures below a certain threshold.

The threshold for what USEPA considers an acceptable increase in risk from a specific exposure is 10^{-6}, or a one-in-one-million chance of getting cancer. The acceptable incremental risk level established by Washington Department of Ecology is 10^{-5}, or one in 100,000. As a point of comparison, for the entire U.S. population, the probability that someone in that population will get cancer during their lifetime is 1 in 3 and if that individual is a smoker, the odds increase to 2 in 3.

Risks are estimated by multiplying a numerical estimate of ***the exposure*** by a numerical estimate of ***the toxicity*** of that chemical The exposure estimate was based on a characterization of 1) exposure populations, 2) exposure routes (ie. ingestion or direct contact), and 3) exposure concentrations. These were combined to determine a single estimate of exposure for each exposed population. For this project, toxicity values for PAHs were USEPA-derived values using data from the scientific literature for both non-carcinogenic effects and carcinogenic effects of PAHs. Finally, risk is calculated by combining the exposure and toxicity estimates. The derivation of exposure and toxicity, as well as the calculations used to estimate risk are summarized in Sections 6.2 and 6.3.

6.1.1 Evaluation Criteria

Human health risks were evaluated for both carcinogenic PAHs and for non-carcinogenic PAHs. Evaluation criteria for this study were those provided in USEPA guidance for conducting HHRAs (USEPA 1989). For carcinogenic PAHs, the threshold used in this study was 10^{-6}, or one in 1,000,000. For non-carcinogenic PAHs, their toxicity was compared directly to concentrations known to cause toxicity in humans. This was done using a hazard index (HI), which is simply a ratio of the average daily dose of PAHs that people are exposed to at the site compared to doses of PAHs that are known to cause human health effects (reference dose). If the dose at the site is less than the reference dose, the HI is less than 1, indicating that human health effects are unlikely (USEPA 1989). The derivation for the carcinogenic and non-carcinogenic evaluation criteria are explained more fully in the following sections.

6.2 Exposure Assessment

As mentioned above, the exposure estimate was based on a characterization of exposure populations, exposure routes, and exposure concentrations. This section provides an overview of each of these components of the exposure assessment.

6.2.1 Exposure Populations

Two exposure populations were evaluated under the conditions prior to piling removal and under conditions present after piling removal. These populations are as follows:

> *Commercial exposure population* – the exposed populations consist of adults and children in the general public who consume shellfish from the former log yard.
> *Tribal exposure population* – the exposed populations consist of tribal adults and children who both harvest and consume shellfish from the former log yard.

6.2.2 Exposure Scenarios

The exposure scenario describes the ways in which humans are exposed to the chemical contaminants and includes the exposure pathways and routes of exposure. Exposure scenarios are comprised of one or more exposure routes for this site that are appropriate to the potentially exposed population. The exposure route is the way in which a chemical comes in contact with a human body.

The exposure scenarios for the exposed populations were as follows:

Commercial (General Public) Scenario

- General public adults and children who consume shellfish from the log yard area;

Tribal Member Scenario

- Tribal adults and children who harvest shellfish who are exposed to PAHs in sediments during harvesting;
- Tribal adults and children who consume shellfish from the log yard area;

6.2.3 Exposure Routes

The exposure routes were specific to the exposure scenarios above and included:

- Consumption (ingestion) of contaminated shellfish from the log yard area – applied to Commercial and Tribal scenarios;
- Incidental consumption (ingestion) of contaminated sediment during harvesting activities (*this includes sediment that Tribal members might accidentally consume when they are harvesting clams*) – applied only to the Tribal scenario;
- Skin (dermal) contact with contaminated sediment, followed by absorption of PAHs across the skin (*this includes PAHs in the sand directly contacting the skin*) – applied only to the Tribal scenario.

6.2.4 Exposure Point Concentrations

Exposure point concentrations are the concentrations of PAHs that were found or were predicted to be in either the clam tissues or sediment that the exposure populations may contact. For the general public this was limited to the clam tissues. For tribal harvesters, this included both the sediment and clam tissues. It is important to note that exposure concentrations are normalized to organic carbon (for sediment) or lipids (in tissues). This normalization takes into account the fact that PAHs have a propensity to bind to organic carbon or lipids and in this form are generally less available as a toxic agent.

6.2.4.1 Sediments

Exposure-point concentrations of sediment PAHs were measured in the log yard area prior to piling removal and following removal of the pilings. The concentrations used in the risk models were the 95th percentile upper confidence limits of the mean concentration (UCLM; USEPA 1989, Ecology 1992). Exposure point concentrations were developed using the following data sets:

Pre-Removal Conditions: Exposure concentrations were based on the surficial sediment data for direct contact and incidental ingestion.

Post-Removal Conditions: Risks that might be present in clams in clams not available for intertidal sampling were based on PAH concentrations in the surficial sediment collected after piling removal and used the BSAF to predict tissue concentrations. Surficial sediment data were also used to assess direct contact and incidental ingestion.

Sediment data is typically expressed as dry weight; however, the HHRA requires wet weight data. Sediment data was converted to dry weight assuming a moisture content of 50%.

6.2.4.2 Shellfish Tissue

Exposure point concentration data for shellfish pre-removal and post-removal conditions were calculated from PAHs measured in shellfish collected from the former log yard. Although most buyers and tribal consumers will allow clams to void their gut of sediment (depuration) prior to selling or consuming those clams, it is also possible that clams that are not depurated will be consumed. As a conservative estimate of risk, shellfish for this analysis were not depurated. Exposure point concentrations of PAHs in shellfish were the 95th percentile upper confidence limits of the mean concentration. Percent moisture of the shellfish for calculating wet weight concentrations for use in the exposure assessment was assumed to be 82% (USEPA 1997).

For post-removal conditions, tissue concentrations were estimated in two ways. To estimate clam tissues that exist on the available intertidal area following piling removal tissue concentration were measured directly, as described above. For post-removal conditions in areas not available during the post-removal survey, but that may be harvestable in the future, tissue concentrations were estimated using a sediment to tissue relationship, based on the PAH concentrations in the sediment following piling removal. The sediment to tissue relationship used to predict tissue concentrations is called a biota-sediment accumulation factor, or BSAF. It predicts what concentrations clams will accumulate in their tissues when exposed to a certain sediment concentration. The BSAF was based on site-specific, co-located sediment and tissue data collected during the pre-removal survey.

Because PAHs typically bind to organic material in the sediment and lipids in the body, BSAFs are based on lipid content of the biotic tissue and the organic carbon content of the sediment. The BSAF is calculated as follows:

$$BSAF = \frac{Biota(mg/kg\ lipid)}{Sediment(mg/kg\ OC)}$$

Predicted shellfish PAH concentrations were then calculated by multiplying the sediment PAH concentrations in the sediment by the BSAF.

The average lipid fraction of shellfish collected from Sequim Bay was 0.01, which is consistent with values in WDOH (1995) for Puget Sound shellfish. The average organic carbon content of the sediment samples at the former log yard prior to piling removal was 1.4 percent.

To estimate tissue concentrations for "*post-removal*" conditions using the sediment data, the BSAF was applied to sediment samples collected after piling removal was completed.

6.2.5 Exposure Estimation Equations

The final step in the exposure assessment is the estimation of chemical intake and resulting dose for each chemical using each of the exposure pathways. The extent of potential intake through the various pathways is dependent on an individual's location and behavior. Pathways include incidental ingestion of sediment, dermal contact with sediment, and ingestion of shellfish. A series of conservative assumptions are made to calculate chemical intakes that yield high conservative estimates of potential exposures.

For long-term (i.e., subchronic and chronic) exposures to noncarcinogenic chemicals, intakes are averaged over the period of exposure (i.e., the averaging time, AT), and are referred to as the average daily dose (ADD) (USEPA 1989). For carcinogens, intakes are averaged over an entire lifetime and are referred to as the lifetime average daily dose (LADD) (USEPA 1989).

The equations used to estimate intakes for each of the exposure pathways follow USEPA (1989, 2004b) guidance:

Incidental Ingestion of Sediment:

$$(L)ADD = \frac{C_{sed} \ x \ IR_{sed} \ x \ EF \ x \ ED}{BW \ x \ AT} \ x \ CF$$

Dermal Contact with Sediment:

$$(L)ADD = \frac{C_{sed} \ x \ SA \ x \ AF \ x \ DAF \ x \ EF \ x \ ED}{BW \ x \ AT} \ x \ CF$$

Ingestion of Shellfish:

$$(L)ADD = \frac{C_f \ x \ IR_f \ x \ F_f \ x \ EF \ x \ ED}{BW \ x \ AT} \ x \ CF$$

where:

(L)ADD	=	(Lifetime) Average daily dose (mg/kg-day)
C_{sed}	=	Concentration of chemical in sediment (mg/kg)
IR_{sed}	=	Intake rate of sediment, ingestion (mg/day)
SA	=	Surface area of skin contact (cm^2/event)
AF	=	Adherence factor for sediment-to-skin (mg/cm^2)
DAF	=	Dermal absorption factor (unitless)
C_f	=	Concentration of chemical in shellfish (mg/kg)
IR_f	=	Ingestion rate of shellfish (mg/day)
F_f	=	Fraction of shellfish obtained from the area (unitless)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (days)
CF	=	Conversion factor (10^{-6} kg/mg).

6.2.6 Exposure Factor Values

Values for the exposure factors used in the exposure estimates are shown in Table 6.1. Factors were taken from Ecology (1999) and USEPA (1997, 2004b) guidance and values provided by the Jamestown S'Klallam Tribe (Kelly Toy, personal communication). Exposure values are identified for each exposure scenario.

It should be pointed out that the exposure factors for the Tribal scenario are intended to reflect exposures specific to Jamestown S'Klallam tribal members. However, there were no formal exposure studies conducted for this investigation. Where Tribal data were unavailable, values provided by USEPA and Washington Department of Ecology were used.

Commercial scenario – For the general US population, individuals were assumed to be exposed to PAHs only from commercially sold shellfish harvested in the former log yard. Risks to both adults and children are evaluated under this scenario. Shellfish ingestion rates for the general population were 1.4 g/day for adults and 0.8 g/day for children (Table 10-6 of USEPA 1997).

Tribal scenario – Shellfish are harvested from Sequim Bay for both commercial sale and subsistence fisheries. This risk assessment included tribal members only consume shellfish, as well as those who may harvest and consume shellfish from the former log yard area. It was assumed that the shellfish harvester would visit the sediments of the former log yard 20 and 5 days per year, for adults and 5 days per year for children. The incidental ingestion rate of sediment during harvesting was assumed to be one-half the rate for soils in USEPA (1997), at 50 mg/day and 200 mg/day for adults and children, respectively. The adherence factor for dermal contact with sediment was assumed to be the same as for soil, and was taken from USEPA (2004b).

The shellfish ingestion rate of 68 g/day was used for tribal adults (Kelly Toy, personal communication; Ecology 1999). The ingestion rate for tribal children of 34 g/day was assumed to be one-half the adult ingestion rate, consistent with the ratio of child to adult ingestion rates for the general US population (USEPA 1997). It is important to note that for the pre-removal assessments, it was assumed that 100% of the clam consumption will come from the log yard and/or the south Sequim Bay commercial and subsistence sites. For the post-removal assessment, that value was reduced to 50% based on tribal harvest records in Sequim Bay (Kelly Toy, personal communication).

Table 6.1. Exposure Parameter Values

Variable	Definition	Unit	Adult		Child	
			Comm.	Tribal	Comm.	Tribal
	Ingestion of Sediment					
CR	Ingestion Rate	mg/day	0	50	0	200
EF	Exposure Frequency	day/yr	0	20	0	10
ED	Exposure Duration	yr	9	30	6	6
BW	Body Weight	kg	70	70	15	15
AT-NC	Averaging time - Noncancer	days	3,285	10,950	2,190	2,190
AT-C	Averaging Time - Cancer	days	25,550	25,550	25,550	25,550
CF	Conversion Factor	kg/g	1.00E-06	1.00E-06	1.00E-06	1.00E-06
	Dermal Contact with Sediment					
SA	Surface Area for Contact	cm^2	5,200	6,900	4,500	5,000
AF	Adherence Factor	mg/cm^2	0.2	0.2	0.2	0.2
EF	Exposure Frequency	day/yr	0	20	0	5
ED	Exposure Duration	yr	9	30	6	6
BW	Body Weight	kg	70	70	15	15
AT-NC	Averaging time - Noncancer	days	3,285	10,950	2,190	2,190
AT-C	Averaging Time - Cancer	days	25,550	25,550	25,550	25,550
CF	Conversion Factor	kg/mg	1.00E-06	1.00E-06	1.00E-06	1.00E-06
	Ingestion of Shellfish					
CR	Ingestion Rate	g/day	1.4	68	0.8	34.0
EF	Exposure Frequency	day/yr	365	350	365	350
ED	Exposure Duration	yr	30	30	6	6
F_f	Fraction from Site	unitless	0.5	0.5	0.5	0.5
BW	Body Weight	kg	70	70	15	15
AT-NC	Averaging time - Noncancer	days	10,950	10,950	2,190	2,190
AT-C	Averaging Time - Cancer	days	25,550	25,550	25,550	25,550
CF	Conversion Factor	kg/g	1.00E-03	1.00E-03	1.00E-03	1.00E-03

Notes:
Exposure parameter values from USEPA (1997, 2004a), except where noted below: Central tendency values used for Commercial Scenario; Reasonable Maximum Exposure values used for Tribal Scenario

One-half soil ingestion rates used for sediment ingestion

Adherence factor based on soils

Ingestion rates for shellfish, tribal, are from Ecology (1999). Child rates based on one-half adult rates.

Ingestion rates for shellfish, commercial, are from USEPA (1997, Table 10-6).

6.3 Toxicity Assessment

While the Exposure Assessment provides an estimate of how much of the creosote-related PAHs that the general public and Tribal members may be exposed to, the Toxicity Assessment provides an indication of how toxic those creosote-related PAHs may be.

The Toxicity Assessment is based on three factors:

- The types of potential adverse health affects associated with PAH exposures;
- The relationship between the magnitude of exposure and the adverse effects; and
- The related uncertainties associated with our understanding of this relationship.

Most petroleum products occur as a complex mixture of individual PAHs. This toxicity assessment relied on toxicity data for key PAHs known to occur in creosote. USEPA has evaluated existing toxicity information and characterized the relationship between the dose of the chemical received and the incidence of potentially adverse health effects in the exposed population. From this quantitative dose-response relationship, specific toxicity values were derived that can be used to estimate the incidence of adverse effects at different exposure levels (USEPA 1989). These toxicity values are called reference doses (RfDs) for non-carcinogens and slope factors (SFs) for potential carcinogens.

USEPA has identified seven PAHs as carcinogenic, for which slope factors have been derived (Table 6.2). For the remaining PAHs, only non-cancer effects are evaluated.

Table 6.2 List of Carcinogenic and Non-Carcinogenic Polycyclic Aromatic Hydrocarbons

Carcinogenic	Non-Carcinogenic
Benzo(a)anthracines	Naphthalene
Chrysene	Acenaphthylene
Benzo(b)fluoranthene	Anthracene
Benzo(k)fluoranthene	Acenaphthene
Benzo(a)pyrene	Fluorene
Indeno(1,2,3-cd)pyrene	Phenanthrene
Dibenz(a,h)anthracene	2-Methylnaphthalene
	Fluoranthene
	Pyrene
	Benzofluoranthenes
	Benzo(g,h,i)perylene

6.3.1 Reference Doses for Non-carcinogens

As stated above, a reference dose is used to evaluate non-cancer toxicity. Non-cancer causing PAHs are thought to have thresholds, below which toxic effects are not expected. These thresholds are called reference doses (RfDs). RfDs are expressed in units of milligrams of chemical per kilogram of body weight per day (mg/kg-bw/day). They are derived from either animal laboratory experiments or human epidemiology investigations (usually workplace studies), and include uncertainty factors to account for specific types of uncertainty inherent in extrapolation from the available data. The toxicity values used for non-carcinogenic contaminants of potential concern (COPCs) are presented in Table 6.3.

For all PAHs, toxicity values for non-carcinogens were taken, when available, from the Integrated Risk Information Systems (IRIS) database. IRIS is a broad database maintained by the USEPA that includes dose-response data for many chemicals. If toxicity values for PAHs were not available from IRIS, the USEPA Region 3 Risk-Based Concentrations tables were consulted (USEPA 2004a). The Region 3 tables contain updated toxicity criteria from the USEPA National Center for Exposure Assessment that have not undergone the peer review process that is part of the listing in the IRIS database.

6.3.2 Slope Factors for Carcinogens

Unlike non-carcinogens, carcinogens are generally assumed to have no threshold. This "non-threshold" concept supports the idea that there are small, finite probabilities of inducing a carcinogenic response associated with every level of exposure to a potential carcinogen. This is expressed as a gradually increasing dose-response curve that starts at zero. The x-axis is defined as the daily intake of a chemical over a lifetime and the y-axis is the probability of developing cancer. The slope of this curve is then used to determine what effect (cancer) is related to what dose. The slope-factor is the upper 95th percentile of the slope of the cancer dose-response curve (USEPA 1989). The toxicity values used for carcinogenic PAHs are presented in Table 6.3**.**

Slope factors are generally based on experimental animal data, unless suitable epidemiological studies are available. Due to the difficulty in detecting and measuring carcinogenic endpoints at low exposure concentrations, slope factors are typically developed by using a numerical model to fit the available high-dose, experimental animal data, and then extrapolating downward to the low-dose range to which humans are typically exposed. The models used by USEPA are conservative and provide an upper bound estimate of excess lifetime cancer risk. Thus, the actual risk may be lower and could be zero (USEPA 1989). There is a high degree of uncertainty in these extrapolations, so uncertainty factors are used to generate conservative estimates of cancer risk.

6.3.3 Uncertainty Factors

Uncertainty factors are included in RfDs and slope factors because available toxicity data are often based on animal models or human clinical studies that have different exposure scenarios. Uncertainty factors reduce the estimated dose that will cause an effect, typically by a factor of 10, 100, 1,000, or 10,000. The magnitude of the uncertainty factors is related to the confidence in the data set (for example, animal studies have a larger uncertainty factor than for human studies). The use of these factors is a conservative approach to protection of human health and is likely to overestimate the risks that are associated with chemical exposure.

Table 6.3 Toxicity Values for Carcinogenic and Non-carcinogenic PAHs

	Reference Dose	**Cancer Slope Factor**	**Reference Dose**	**Cancer Slope Factor**	**GI Absorption Factor**	**Dermal Absorption Factor**
	Oral	Oral	Dermal	Dermal	GI ABS	DAF
Chemical	(mg/kg-day)	per (mg/kg-day)	(mg/kg-day)	per (mg/kg-day)	Unitless	Unitless
PAH						
Naphthalene	2.00E-02	NA	2.00E-02	NA	1	0.13
2-Methylnaphthalene	4.00E-03	NA	4.00E-03	NA	1	0.13
Acenaphthylene	6.00E-02	NA	6.00E-02	NA	1	0.13
Acenaphthene	6.00E-02	NA	6.00E-02	NA	1	0.13
Fluorene	4.00E-02	NA	4.00E-02	NA	1	0.13
Phenanthrene	3.00E-01	NA	3.00E-01	NA	1	0.13
Anthracene	3.00E-01	NA	3.00E-01	NA	1	0.13
Fluoranthene	4.00-02	NA	4.00E-02	NA	1	0.13
Pyrene	3.00E-02	NA	3.00E-02	NA	1	0.13
Benz(a) anthracene	NA	7.30E-01	NA	7.30E-01	1	0.13
Chrysene	NA	7.30E-03	NA	7.30E-03	1	0.13
Benzo (b) fluoranthene	NA	7.30E-01	NA	7.30E-01	1	0.13
Benzo (k) fluoranthene	NA	7.30E-02	NA	7.30E-02	1	0.13
Benzo (a) pyrene	NA	7.30E+00	NA	7.30E+00	1	0.13
Indeno (1,2,3 –cd) pyrene	NA	7.30E-01	NA	7.30E-01	1	0.13
Dibenz (a, h) anthracene	NA	7.30E+00	NA	7.30E+00	1	0.13
Benzo (g, h, i) perylene	4.00E-02	NA	4.00E-02	NA	1	0.13
Dibenzofuran	2.00E-03	NA	2.00E-03	NA	1	0.13

Anthracene values used for phenanthrene; Acenaphthene values used for acenaphthylene; Fluoranthene values used for benzo(g,h,i)perylene

Values from US EPA IRIS database, or US EPA National Center for Exposure Assessment, as cited by US EPA Region 3 (2004a)

NA, not available

6.4 Risk Characterization

Risk characterization is the final step of the human health risk assessment process. In this step, the exposure concentrations were combined with toxicity data to quantitatively estimate both carcinogenic risks and risks for non-carcinogens.

The methodologies used to estimate the chronic and sub-chronic risks for non-carcinogens and the cancer risk for carcinogens are described below.

6.4.1 Hazard Index for Noncarcinogenic Effects

The potential human health risks associated with exposures to non-carcinogenic chemicals were estimated by comparing the average daily dose (ADD) with established reference dose (RfDs) (USEPA 1989). This comparison is called a hazard quotient (HQ) and is simply a ratio of the dose that is predicted at the site divided by a dose that is known to cause effects in humans. The HQ was derived for each non-carcinogenic PAH using the following equation:

$$HQ = \frac{ADD}{RfD}$$

where: HQ = Hazard Quotient (unitless)
ADD = Estimated average daily dose (mg/kg-day)
RfD = Reference dose (mg/kg-day).

If ADD is greater than the RfD, then the hazard quotient is >1.0 and adverse health effects may be observed in the exposed populations (USEPA 1989). If the ADD is less than the RfD, the HQ <1.0 and there is no concern of adverse health effects in the exposed populations. In general, the more the HQ is above 1.0, the greater the level of concern. It is important to note that the HQ does not represent a statistical probability that an adverse health effect will occur. For PAHs, the HQs from each individual PAH are summed to calculate a Hazard Index (HI), which is then compared to 1.0. As with the hazard quotient, if the HI is less than 1.0, the level of risk from non cancer-causing PAHs is considered to be acceptable.

6.4.2 Cancer Risks

Carcinogenic risk was estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen at the site. The numerical estimate was calculated by multiplying the lifetime average daily dose (LADD) by the slope factor.

Because the slope factor is the statistical 95th percent upper confidence limit on the slope of the dose-response curve, this method provides a conservative, upper-bound estimate of risk.

6.5 Results of the Pre-removal HHRA

The exposure point concentrations, PAH concentrations that the exposure population might be exposed to prior to piling removal, are presented in Table 6.4. Risk estimates were developed separately for adult and child exposures, for both cancer and non-cancer risks (Table 6.5). The total cancer risk was estimated with non-detected levels of benzo(a)pyrene and other carcinogenic PAHs in shellfish included at one-half their detection limits.

As defined above, the threshold for acceptable risk for cancer-causing PAHs was 10^{-6} (USEPA 1986). The threshold for the calculated hazard index for non-cancer-causing PAHs was 1.0 (USEPA 1986).

6.5.1 Commercial Shellfish Ingestion

The total cancer risk for public consumption of all PAHs detected in shellfish was estimated at 1.5 $x10^{-8}$ for adults. For children, this estimated risk was 8.2 $x10^{-9}$. These estimates of risk were below the acceptable risk threshold of 10^{-6}, indicating that prior to piling removal, consumption of shellfish from the former log yard by the general public did not present an unacceptable cancer risk.

The potential health effects of combined doses of non-carcinogen were evaluated by calculating the cumulative Hazard Index (HI) for all non-carcinogenic PAHs. The total HI for non-cancer health effects for adults was estimated at 0.00008 and the HI for children was 0.0002. Both values were substantially less than 1.0, indicating an acceptable level of risk from commercial consumption of shellfish from the former log yard prior to piling removal.

6.5.2 Tribal Shellfish Harvesting and Ingestion

The total cancer risk for adults harvesting and ingesting shellfish prior to piling removal was estimated at 7.2 $x10^{-7}$. Ingestion of shellfish accounted for approximately 99% of the cumulative excess lifetime cancer risk for the tribal adult, with direct contact or ingestion of sediment comprising approximately 1% of the total risk. The adult cancer risk associated only with harvesting shellfish was 3.9 $x10^{-8}$. The total cancer risk for children harvesting and ingesting shellfish was estimated at 3.5 $x10^{-7}$. The estimated risk associated with children harvesting shellfish was 2.6 $x10^{-8}$. Results indicated that prior to removal, consumption of shellfish from the former log yard by the tribal members did not present an unacceptable cancer risk.

The total HI for chronic non-cancer health effects for adult tribal members was 0.0038 for harvesting and ingesting shellfish. The non-cancer HI for children was 0.0089. These results were well below 1.0, indicating an acceptable level of risk from Tribal harvest and consumption of shellfish from the former log yard prior to piling removal.

Table 6.4. Risk Assessment Summary Statistics for PAHs in Pre-Removal Surficial Sediment and Tissues

	Pre-Removal Surficial Sediment			Pre-Removal Clam Tissue		
Chemical of Potential Concern	**Maximum Detected Concentration** (µg/kg wet wt)	**Detection Frequency**	**95% UCL of Arithmetic Mean** (µg/kg wet wt)	**Maximum Detected Concentration** (µg/kg wet wt)	**Detection Frequency**	**95% UCL of Arithmetic Mean** (µg/kg wet wt)
PAHs						
Naphthalene	5	0.1	3.1	--	0.0	0.9
2-Methylnaphthalene	5	0.0	2.3	--	0.0	0.9
Acenaphthylene	13	0.3	7.1	--	0.0	0.9
Acenaphthene	110	0.4	60.7	3.4	0.1	1.7
Fluorene	115	0.4	57.1	5.8	0.3	2.7
Phenanthrene	750	0.7	355.2	25.2	0.6	13.0
Anthracene	80	0.6	43.3	4.1	0.2	2.2
Fluoranthene	1,400	0.8	733.2	63.0	0.8	32.5
Pyrene	750	0.9	386.1	36.0	0.6	18.6
Benz(a) anthracene	130	0.8	77.0	3.6	0.2	2.0
Chrysene	270	0.8	152.3	3.4	0.3	2.2
Benzo (b) fluoranthene	110	0.8	61.7	--	0.0	0.9
Benzo (k) fluoranthene	80	0.7	45.6	--	0.0	0.9
Benzo (a) pyrene	43	0.6	24.5	--	0.0	0.9
Indeno (1,2,3 –cd) pyrene	14	0.3	8.3	--	0.0	0.9
Dibenz (a, h) anthracene	2	0.0	2.3	--	0.0	0.9
Benzo (g, h, i) perylene	12	0.3	7.0	--	0.0	0.9
Dibenzofuran	60	0.3	30.1	4.7	0.1	2.1

Table 6.5. Summary of Cancer and Non-cancer Risks – Pre-Removal Conditions

Scenario	Public Consumption of Shellfish	Tribal Harvester - Incidental Ingestion of Sediment	Tribal Harvester - Dermal Contact with Sediment	Total Tribal Harvester	Tribal Ingestion of Shellfish	Total Tribal Harvester and Ingestion
Adult – Current Conditions						
Cancer risk	1.5E-08	8.5E-09	3.0E-08	3.9E-08	6.8E-07	7.2E-07
Noncancer risk	0.00008	0.000004	0.00001	0.00002	0.0038	0.0038
Child – Current Conditions						
Cancer risk	8.2E-09	1.6E-08	1.0E-08	2.6E-08	3.2E-07	3.5E-07
Non-cancer risk	0.0002	0.000004	0.00001	0.00002	0.0088	0.0089

Cancer Risk Threshold = 10^{-6}
Non-Cancer Risk Threshold = 1.0

6.6 Post-Removal Human Health Risk Assessment

Post-removal risk was assessed in two ways. First, to assess the risk associated with the harvest and consumption of intertidal clams available following piling removal, tissue-PAH concentrations were compared to tissue-PAH concentrations observed in during the pre-removal risk assessment.

In order to evaluate potential risk for those areas of the former log yard that were not accessible during the post-removal evaluation, but that may support future shellfish harvest, a second assessment was conducted using PAH concentrations observed in post-removal sediments and biota-sediment accumulation factors (BSAFs) derived from the co-located sediment and tissue samples from the pre-removal assessment.

6.6.1 HHRA Based on Post-Removal Tissues

PAHs were undetected in nearly all post-removal clam tissue samples collected in the former log yard and vicinity (Table 5.4). None of the cancer-causing PAHs were detected in any of the clam tissue samples. Three of the non-carcinogenic PAHs, (phenanthrene, fluoranthene, and pyrene) were detected at concentrations very near the limits of detection and well below those observed in the pre-removal tissue samples.

Based on the lack of any detectable levels of carcinogenic PAHs in the existing clam tissue, there would be no unacceptable increased cancer risk to tribal members or the public from the consumption of clams currently found in the former log yard. Based on the very low concentrations of non-carcinogenic PAHs observed in the post-removal clam tissues, the HI would be predicted to be below 1.0, indicating an acceptable level of risk to the general public or Tribal members from non-cancer-causing PAHs.

Post removal sediment concentrations were also dramatically lower than those of the pre-removal samples that were collected near the pilings. Because of these low concentrations and the fact that exposure of harvesters to sediment (through contact or incidental ingestion) only contributes approximately 1% to the total tribal risk, there would be no significant increase in the human health risk to tribal members from sediment exposure.

6.6.2 HHRA Based on Post-Removal Sediments

In order to estimate human health risk based on sediment PAH concentrations, post-removal sediment PAHs concentrations were first converted to estimated tissue concentrations based on a sediment to tissue relationship, the BSAF, as explained in Section 6.2.4.2.

6.6.2.1 Biota-Sediment Accumulation Factor Derivation

Average BSAFs were calculated for each PAH that was detected in the clam tissues (Table 6.6). There was a wide range in calculated BSAFs was found for many of the PAHs. The pool of average BSAFs for each PAH were found to be curvilinear with respect to organic carbon-normalized PAH concentrations in sediment. This indicated that one BSAF conversion value could not be used for all PAHs. Rather an individual BSAF was calculated for each PAH using the following equation:

$$BSAF = 288.47*(PAH_{OC})^{-0.7454}$$

The modeled BSAFs based on this curvilinear relationship are presented in Table 6.6. A more thorough discussion of the BSAF derivation is presented in Appendix A.

The BSAFs were derived on a dry weight basis from sediment and shellfish data. Modeled concentrations of PAHs in shellfish were initially calculated on a dry weight basis, which were converted to wet weight by assuming percent moisture content of 82 percent, as presented for clams in Table 10-6 of USEPA (1997).

Table 6.6 Site-Specific BSAFs Calculated for PAHs

		Undepurated BSAFs (n=9)		
Chemical of Concern	**K_{ow}**	**Min.**	**Max.**	**Average**
Naphthalene	$2.36x10^3$	ND	ND	**ND**
2-Methylnaphthalene	$9.81x10^3$	ND	ND	**ND**
Acenaphthylene	$8.95x10^3$	ND	ND	**ND**
Acenaphthene	$9.22x10^3$	1.2	1.2	**1.2**
Fluorene	$1.47x10^4$	0.03	2.1	**0.8**
Phenanthrene	$3.55x10^4$	0.02	1.4	**0.4**
Anthracene	$2.95x10^4$	0.03	1.2	**0.6**
Fluoranthene	$1.21x10^5$	0.02	1.4	**0.5**
Pyrene	$1.00x10^5$	0.02	0.9	**0.4**
Benz(a) anthracene	$4.77x10^5$	0.02	0.3	**0.2**
Chrysene	$5.48x10^5$	0.01	0.1	**0.05**
Benzo (b) fluoranthene	$1.59x10^6$	ND	ND	**ND**
Benzo (k) fluoranthene	$1.56x10^6$	ND	ND	**ND**
Benzo (a) pyrene	$1.35x10^6$	ND	ND	**ND**
Indeno (1,2,3 –c, d) pyrene	$8.22x10^6$	ND	ND	**ND**
Dibenz (a, h) anthracene	$3.53x10^6$	ND	ND	**ND**
Benzo (g, h, i) perylene	$1.00x10^7$	ND	ND	**ND**
Dibenzofuran	$1.34x10^4$	ND	ND	**ND**

ND = not detected in sediment or tissue of co-located samples.
K_{ow} values from USEPA (1998) and means of values in Mackay et al. (1992).
BSAFs were calculated from co-located sediment and shellfish samples, of depurated and undepurated shellfish.

6.6.4.1 Post-Removal Commercial Shellfish Ingestion

Based on the BSAFs and the post-removal sediment PAHs, the total cancer risk for adult public consumption of shellfish under post-removal conditions was estimated at 1.0 $x10^{-7}$ (Tables 6.7 and 6.8). The estimated risk for children was estimated at 7.0 $x10^{-8}$. Results indicate that consumption of shellfish from the former log yard by the adults and children of the general public following piling removal did not present an unacceptable cancer risk (<10^{-6}).

The total HI for non-cancer health effects was estimated at 2 $x10^{-6}$ for adults and 7 $x10^{-6}$ for children. These results were well below 1.0 and indicated an absence of non-cancer risks from adults and children of the general population who may consume shellfish from the former log yard following piling removal.

6.6.4.2 Post-Removal Tribal Harvest and Ingestion

The total cancer risk for adult tribal members from the harvest and consumption of shellfish under post-removal conditions was estimated at 5.5 $x10^{-6}$. The predicted future risk for children was estimated at 3.0 $x10^{-6}$. However, these calculated risks were driven by the detected levels of benzo(a)pyrene in sediment and modeled concentrations in shellfish tissue. However, benzo(a)pyrene was not detected in any tissue samples collected prior to or after piling removal. This includes clams co-located with benzo(a)pyrene sediment concentrations an order of magnitude higher than the concentration observed in the post-removal sediment. If benzo(a)pyrene is removed from the risk calculation, the calculated risk for adults would be 9.1 $x10^{-7}$ and for children would be 4.2 $x10^{-10}$. Based on the data from the former log yard, removal of benzo(a)pyrene from the calculation better predicts risk at this site.

The total HI for non-cancer health effects for harvesting and ingesting shellfish was estimated at 1 $x10^{-4}$ for adults and 3 $x10^{-4}$ for children. These results were well below 1.0 and indicated an acceptable level of non-cancer risk to adults and children of the general public or Tribe who may harvest and/or consume shellfish from the former log yard following piling removal.

Table 6.7 Modeled Concentrations of PAHs in Shellfish, Post-Removal Conditions

PAH	Maximum or 95% UCL Concentration in Sediment (Csb) (µg/kg dry)	OC-Normalized Concentration in Sediment (µg/kg OC dry)	Shellfish BSAF (unitless)	Cshellfish (µg/kg dry)	Cshellfish (mg/kg dry)	Cshellfish (mg/kg wet)
Naphthalene	ND	ND	-	-	-	-
2-Methylnaphthalene	ND	ND	-	-	-	-
Acenaphthylene	ND	ND	-	-	-	-
Acenaphthene	ND	ND	-	-	-	-
Fluorene	ND	ND	-	-	-	-
Phenanthrene	33.3	3,933.8	0.6	24.10	0.024	0.0043
Anthracene	5.9	704.2	2.2	15.55	0.016	0.0028
Fluoranthene	143.4	799.5	2.0	16.06	0.016	0.0029
Pyrene	100.6	3,933.8	0.6	24.10	0.024	0.0043
Benz(a) anthracene	17.6	874.5	1.9	16.44	0.016	0.0030
Chrysene	33.0	799.5	2.0	16.06	0.016	0.0029
Benzo (b) fluoranthene	15.0	799.5	2.0	16.06	0.016	0.0029
Benzo (k) fluoranthene	19.0	2,125.0	1.0	20.60	0.021	0.0037
Benzo (a) pyrene	7.0	1,125.0	1.5	17.52	0.018	0.0032
Indeno (1,2,3 –cd) pyrene	ND	ND	-	-	-	-
Dibenz (a, h) anthracene	ND	ND	-	-	-	-
Benzo (g, h, I) perylene	ND	ND	-	-	-	-
Dibenzofuran	ND	ND	-	-	-	-

ND = Not detected in any sediment sample; BSAF not derived.

Undetected concentrations set at one-half detection limit

Cshellfish = (Csb x Flipid x BSAF)/OCsed

Cshellfish = Chemical concentration in shellfish (mg/kg)

Csb = Concentration of chemical in surficial sediment (mg/kg)

Flipid = Shellfish lipid content during pre-removal conditions (mean of 0.01)

BSAF = Biota to sediment accumulation factor (unitless); BSAFs developed from co-located sediment and shellfish samples during the Pre-Removal Evaluation

OC = Fraction of organic carbon in bottom sediment (unitless)

Percent moisture of shellfish was assumed to 82 percent (USEPA 1997).

Table 6.8 Summary of Cancer and Non-cancer Risks Post-Removal Conditions

Scenario	Public Consumption of Shellfish	Tribal Harvester - Incidental Ingestion of Sediment	Tribal Harvester - Dermal Contact with Sediment	Total Tribal Harvester	Tribal Ingestion of Shellfish	Total Tribal Harvester and Ingestion
Adult						
Cancer risks	1.0 E-07	3.0 E-10	1.0 E-09	1.5 E-09	**9.1 E-7**	**9.1 E-7**
Non-cancer risks	2.0 E-06	7.0 E-08	2.0 E-07	3.0 E-07	1.0 E-04	1.0 E-04
Child						
Cancer risks	7.0.E-08	6.0 E-10	4.0 E-10	1.0 E-09	**4.0 E-10**	**4.2 E-10**
Non-cancer risks	7.0 E-06	6.0 E-07	4.0 E-07	1.0 E-06	3.0 E-04	3.0 E-04

Based on sediment data collected after removal of pilings, and shellfish tissue concentrations predicted from the sediment data

Bold values indicate risk values calculated with the modeled concentrations of benzo(a)pyrene excluded. Benzo(a)pyrene was not detected in any tissue samples collected during this study (see Section 6.6.4.2).

7.0 Discussion

This section provides a discussion of the general sediment characteristics of the log yard, the nature and extent of PAH contamination in sediment and tissues of the log yard and control sites, and estimated human health risk and environmental health risk based on the measured and observed PAH concentrations.

7.1 General Characteristics and PAH Contamination Prior to Removal

Sediment in the log yard is primarily comprised of a moist, olive green to brown finer grained sand, silt, and clay overlying a bed layer of dry, light to dark gray medium-coarse sand. Surface sediment extends to approximately 2 ft. below sediment surface (BSS) and may contain shell hash, woody debris, as well as debris from human activities (i.e. cable, pieces of machinery). Subsurface sediments to at least 8 to 9 ft. BSS typically contain whole shells of both littleneck and *Macoma* spp. clams. There is a very wet sand layer that occurs at 4-6 ft. BSS in four of the 12 stations sampled. This may be run-off from Dean Creek. Sediment from the control sites is a fine to medium coarse sand and more closely resembles that of the subsurface sediments from the log yard. Based on sediment characteristics, it is likely that the surface sediment in the former log yard was recently deposited as the hydrology of the south Bay was altered by human activities.

PAHs were not detected in the control sites east of the log yard prior to piling removal, indicating that PAH contamination from the former log yard activities were not spread throughout the south Sequim Bay. Furthermore, PAHs were also not detected in the surficial sediment within the log yard approximately 48" from the pilings, indicating that the distribution of PAHs in the log yard is highly localized and directly related to the pilings. Surface sediment collected from the immediate vicinity of the pilings had detected PAHs at all stations. Concentrations of total PAHs ranged from <100 µg/kg dw to 383 mg/kg dw. Total PAH concentrations showed a steep gradient away from the pilings, with 2" stations having PAH concentrations on average 29 times that of the 6" stations and 90 times that of the 12" stations. This localized distribution of PAHs is consistent with previous studies of PAH contamination near creosoted pilings (Guyette and Brooks 1998, Poston 2001).

PAHs were further limited in their distribution to surface sediments, with substantially lower concentrations in the compacted sands found below two feet BSS. This was confirmed in the 12" stations that were cored down to a depth of 8 ft. BSS. There was some evidence of hot spots, which appeared to affect subsurface sediment as well as surface sediment. This was indicated by free product observed in Station E3-12. The distribution of PAHs in the log yard were not associated with

piling type and geographic trends appeared to be driven by hot spots more than by true differences between intertidal and subtidal areas.

This dataset fills in a hole in the existing data regarding the horizontal distribution of PAHs near pilings, with previous studies focusing on sediment between several feet and several hundred feet from the pilings. More importantly, this study indicates that the potential for environmental or human health related impacts are limited to sediment very near the existing pilings.

PAHs were not detected in any of the clam tissues collected from Control Site 1 or 2, indicating that there are no unacceptable human health risks associated with PAHs in clam tissues from the control site. This further indicated that log yard activities did not result in shellfish (clam) contamination in the central and eastern portions of southern Sequim Bay.

Clam tissues collected in the log yard had detected concentrations of PAHs, with the highest concentrations occurring in those clams occurring closest to the pilings. As with the sediments, tissue concentrations were directly related to distance from the pilings with decreasing tissue concentrations with increasing distance. The biota-sediment accumulation factors (BSAFs) indicated a log-normal relationship between tissue concentrations and sediment concentrations.

7.2 Turbidity and PAHs in the Water Column During Removal

Water column monitoring occurred on two of the five days of piling removal activities. Weather was generally calm, currents were light, and the water was relatively clear, with background TSS of approximately 7 to 10 mg/L and turbidity of approximately 6 to 9 NTUs. A fresh breeze was present in the afternoons and sediment transport appeared to be south-southeast as influenced by wave energy.

Based on TSS measurements from fixed OBS sensors, the primary source for sediment resuspension was prop wash from the tug boat as it maneuvered the barge to and from piling removal locations. This influence was increased by "live boating," the use of the tug to continuously hold the barge on location, which was necessitated by the absence of operating spuds to hold the barge in position. TSS concentrations resulting from the tug's prop wash often exceeded 50 to 100 mg/L. To provide some perspective, the Washington State Water Quality Limits for AA waters is 5 NTU (approximately 5 mg/L) above background. Generally, elevated TSS concentrations did not remain for more than five minutes; however, on one occasion, a turbidity plume was observed from the work station to the shore and near the mouth of Jimmycomelately Creek. It should be pointed out that the former log yard is located in very shallow waters and it is not uncommon to have elevated turbidity from wind waves in this area.

Activation of the vibratory hammer generally resulted in increases in TSS, with average TSS concentrations of 25 mg/L (approximately 15 mg/L above background). In some cases, elevated TSS concentrations observed during hammer activity could not be separated from the initial plume from the prop wash. Generally, increases in turbidity during the activation of the vibratory hammer were highly localized, affecting only the OBS sensor within one meter of the piling and not the sensor 5 to 10 meters down-current of the piling being pulled.

The extraction of the piling resulted in greater increases in TSS, with average concentrations of 40 mg/L near the piling and 26 mg/L at the sensor located 5 to 10 meters from the piling (approximately 30 and 16 mg/L above background, respectively). The turbidity plume during extraction, although larger than observed during activation of the vibratory hammer, did appear to be finite; however, it was difficult to determine how long the turbidity plume persisted, because the tug boat prop wash would overwhelm the signal from the piling removal soon after the piling was pulled.

Samples collected at the control site and along a transect in the south Bay indicated that the influence of the piling removal activities was limited to the area between the former log yard and the mouth of Jimmycomelately Creek.

PAHs were observed in the water column during the piling removal process. Generally, PAH concentrations were unchanged or increased slightly during the activation of the vibratory hammer. The highest PAH concentrations were observed during the pull, with visible sheen appearing at the surface. Total PAH concentrations ranged from <1 µg/L to 200 µg/L and typically decreased with distance from the bottom. Elevated PAH concentrations persisted five minutes after the pull; however, the ability to determine trends over time were limited by tug and barge activities. All observed PAH concentrations were below the published Lowest Observable Effects Concentrations of 300 µg/L (NOAA 2003).

7.3 PAH Contamination Following Removal

Surficial sediment was collected from areas within and surrounding the former log yard following removal (September 7, 2005), including samples from the beach west of the former log yard, near the mouth of Jimmycomelately Creek, and the two control stations. PAH concentrations were generally quite low, with concentrations ranging from 0 to 500 µg/kg dw. This is consistent with the surficial samples collected prior to piling removal and indicates that the sediment resuspension that occurred during piling removal did not result in a significant redistribution of creosote contaminated sediments in south Sequim Bay.

7.4 Human Health Risks

Human health risks were evaluated for both pre-removal and post-removal conditions. Two exposure scenarios were evaluated:

- members of the general public who are potentially exposed to PAHs from the former log yard only by eating shellfish from the area; and,
- tribal members who are potentially exposed to PAHs from the former log yard from eating shellfish, from the incidental consumption of contaminated mud during harvesting, and direct contact with potentially PAH contaminated sediment from the former log yard.

Nearly all of the calculated risk was from consumption of shellfish. Very little risk (approximately 1% of the total risk) was associated with ingestion or contact with sediment.

The evaluation criteria were based on USEPA guidance (1986). For cancer-causing PAHs, the threshold for unacceptable risk was 10^{-6}, or 1 in 1,000,000. For non-cancer-causing PAHs, the threshold was a hazard index (HI) greater than 1.0, or an average daily dose that exceeded those previously shown to cause toxicity.

Pre-Removal Conditions: Human health risk prior to piling removal was estimated based on PAH concentrations in clam tissues collected from the former log yard. The calculated human health cancer risks for adults and children prior to piling removal were below the $1x10^{-6}$ cancer risk threshold. The calculated non-cancer risks were all below the 1.0 non-cancer threshold for each of the exposure scenarios. These results indicate that based on pre-removal conditions, the consumption of littleneck clams from the log yard did not present any unacceptable human health (cancer or non-cancer) risk.

Post Removal: Human health risk following removal was estimated based on PAH concentrations in clam tissues, and from sediment PAH concentrations. PAH concentrations observed in clams collected from the former log yard were either not detected, or were detected at very low concentrations. Based on this data, it was concluded that the consumption of littleneck clams from the log yard and vicinity following piling removal does not present any unacceptable human health (cancer or non-cancer) risk.

Sediment-PAH concentrations in samples collected were substantially lower than those collected in the immediate vicinity of the pilings prior to piling removal. This was likely related to the random sampling strategy, which better reflected the human health risk from clam harvesting because tribal members will not preferentially seek out those locations where pilings were once located.

The HHRA conducted with the sediment-PAH values and BSAFs provided an indication of risk from shellfish not available during the post-removal assessment. The risk calculated for Tribal harvest and consumption was 5.5 $x10^{-6}$. However, this value was solely due to a measurable concentration of benzo(a)pyrene in one sediment sample. Benzo(a)pyrene was not observed in any tissue sample, even when the co-located sediment contained higher concentrations of benzo(a)pyrene. Furthermore, studies in fish have found that when BaP is ingested, it is often then eliminated from the body by excretion. BaP was not found to move up the food chain to any degree and did not accumulate in human tissue (Steward et al. 1991). The initial risk estimate was an artifact of the BSAF model used to estimate tissue concentrations. The cancer risk estimate with benzo(a)pyrene removed was well below the USEPA threshold of $1x10^{-6}$ and more accurately estimates the risk from consumption of shellfish from areas of the former log yard not currently accessible for harvest. The calculated non-cancer risks were all below the 1.0 non-cancer threshold for each of the exposure scenarios. These results indicate that based on post-removal sediments, the consumption of shellfish from the log yard would not present any unacceptable human health (cancer or non-cancer) risk.

Based on the post-removal human health risk assessment, the clam and sediment PAH concentrations in former log yard are within the USEPA range of acceptable risk levels for the harvest and consumption of intertidal clams.

7.5 Environmental Health Risks

Environmental health risks were evaluated in the former log yard both prior to and following piling removal. This is particularly relevant considering that the former log yard is expected to be a foraging area for outmigrating juvenile salmonids. In order to evaluate conditions prior to piling removal, the adjusted average PAH concentrations that represent sediment within 6" from the pilings was compared to Washington Department of Ecology Sediment Quality Standards (SQS) and Sediment Cleanup Standards (CSL) (WAC Chapter 173-204) for the marine waters of Washington (Table 7.1). To evaluate the current conditions following piling removal, the surficial sediment data that was analyzed by GC/MS was compared to the State standards (Table 7.2). The SQS values define the degree of sediment quality that is expected to cause no adverse effects to biological resources in Puget Sound sediment. The Cleanup Screening Level (CSL) represents that concentration above which adverse affects are considered to be likely. These values are based on invertebrate effects data collected in Puget Sound. Because the availability of PAHs is affected by the organic carbon content of the sediment, the concentrations for this comparison have been normalized to organic carbon. Also, it is important to note that these values are expressed in ppm, or mg/kg.

Prior to piling removal, concentrations in the former log yard sediments were generally below the SQS levels indicating that adverse biological effects were unlikely. Total LPAH concentrations were below the SQS levels for 10 of the pilings evaluated; whereas sediment from the vicinity of three pilings exceeded the SQS for HPAHs (A2, B3, and E3). Only sediment from pilings B3 and E3 had concentrations exceeded the CSL standards, indicating likely adverse effects. These two stations were considered hot spots and indicated that despite acceptable PAH concentrations throughout much of the area, there are locations where biological effects are likely.

Following piling removal, PAH concentrations were markedly lower, with total LPAH and HPAH concentrations below SQS threshold values in all samples. The difference in concentration is due in part to the random sampling strategy used in the post-removal evaluation; whereas the pre-removal sediment targeted the areas with the highest concentrations. It is presumed that the PAH hot spots observed in the surface sediment prior to removal were not removed by piling removal. However, these sediments comprise a relatively small portion (<20 m^2) of the overall area within the former log yard and do not likely represent a significant environmental risk to invertebrates or fish.

Table 7.1 TOC-Normalized PAH Concentrations (mg/kg) Prior to Piling Removal Compared to Sediment Standards

Analyte	PAHs (mg/kg organic carbon)												
	SQS	CSL	A2	B3	B6	C6	E18	D3	D17	E3	E7	F3	C10
Naphthalene	99	170	1	53	0	0	0	0	0	1	1	0	0
2-Methylnaphthalene	38	64	1	8	0	0	0	0	0	1	1	0	0
Acenaphthylene	66	66	5	15	1	0	1	1	2	15	1	0	0
Acenaphthene	16	57	13	**375**	1	0	2	1	3	**33**	1	1	0
Fluorene	23	79	17	**513**	3	0	4	1	2	9	8	0	0
Phenanthrene	100	480	**213**	**2158**	21	1	46	8	28	**218**	20	1	8
Anthracene	220	1200	23	**134**	1	0	3	3	5	50	52	0	0
Total LPAH	370	780	273	**3256**	27	2	58	13	40	327	85	2	9
Fluoranthene	160	1200	**592**	**2511**	68	8	103	78	**158**	**2883**	105	8	14
Pyrene	1000	1400	**358**	**1452**	41	6	75	55	99	**2377**	95	4	14
Benz(a) anthracene	110	270	**53**	**183**	5	2	9	13	10	**151**	12	1	2
Chrysene	110	460	**117**	**351**	15	5	23	26	27	**401**	28	2	3
Benzo (b) flouranthene Benzo (k) fluoranthene	230	450	76	**253**	8	7	14	20	21	**403**	18	1	2
Benzo (a) pyrene	99	210	17	57	2	1	2	5	4	32	5	0	1
Indeno (1,2,3 –cd) pyrene	34	88	6	16	1	0	1	2	1	12	2	0	0
Dibenz (a, h) anthracene	12	33	2	5	0	0	0	1	0	3	0	0	0
Benzo (g, h, I) perylene	31	78	5	14	1	0	1	2	1	10	2	0	0
Total HPAH	960	5300	**1226**	**4842**	141	31	228	200	322	**6273**	267	17	36

Table 7.2 TOC-Normalized PAH Concentrations (mg/kg) Following Piling Removal Compared to Sediment Standards

Analyte	PAHs (mg/kg organic carbon)											
	SQS	CSL	532	372	337	518	316	353	417	509	C1	C2
Naphthalene	99	170	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
2-Methylnaphthalene	38	64	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Acenaphthylene	66	66	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Acenaphthene	16	57	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Fluorene	23	79	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Phenanthrene	100	480	1.2	<1	<1	<1	6.6	12.0	2.2	1.3	1.3	<1
Anthracene	220	1200	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Total LPAH	370	780	4.3	<1	<1	1.7	9.1	3.2	<1	3.4	4.7	2.4
Fluoranthene	160	1200	1.2	1.4	<1	12.4	10.3	5.0	<1	2.1	1.3	<1
Pyrene	1000	1400	1.2	1.4	<1	<1	5.2	3.7	<1	<1	1.3	<1
Benz(a) anthracene	110	270	1.2	<1	<1	<1	1.3	<1	<1	<1	1.3	<1
Chrysene	110	460	1.2	<1	<1	<1	2.0	1.2	4.8	<1	1.3	<1
Benzo (b) flouranthene	230	450	1.2	<1	<1	<1	<1	<1	2.1	<1	1.3	<1
Benzo (k) fluoranthene			1.2	<1	<1	<1	<1	<1	2.1	<1	1.3	<1
Benzo (a) pyrene	99	210	1.2	<1	<1	<1	<1	<1	1.1	<1	1.3	<1
Indeno (1,2,3 –cd) pyrene	34	88	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Dibenz (a, h) anthracene	12	33	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Benzo (g, h, I) perylene	31	78	1.2	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Total HPAH	960	5300	6.2	5.1	<5	16.9	22.0	13.9	3.2	4.6	6.6	3.5

8.0 References

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