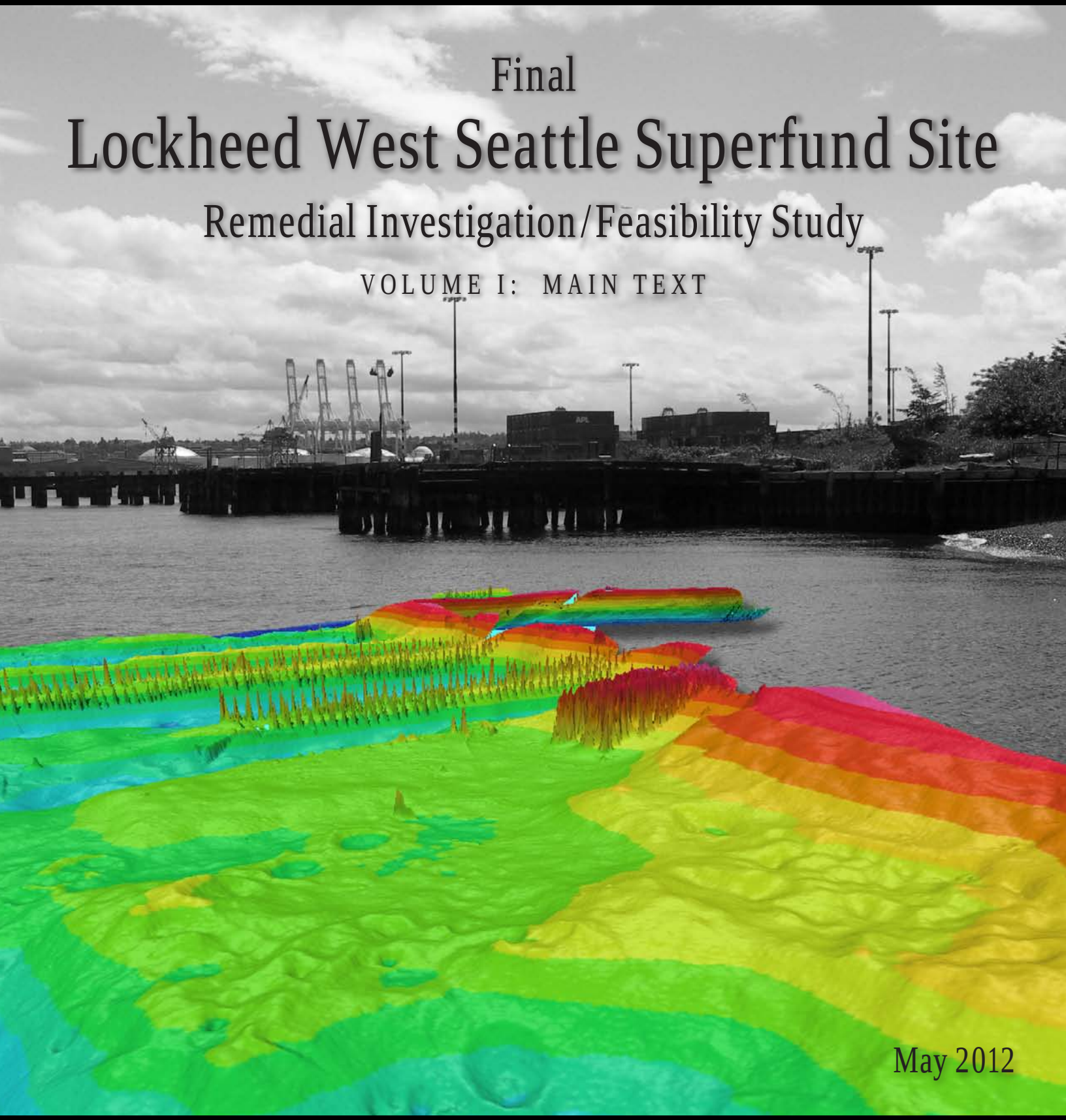
Final

Lockheed West Seattle Superfund Site

Remedial Investigation/Feasibility Study

VOLUME I: MAIN TEXT



May 2012

Prepared for LOCKHEED MARTIN

Prepared by TETRA TECH

FINAL
REMEDIAL INVESTIGATION/FEASIBILITY STUDY
LOCKHEED WEST SEATTLE SUPERFUND SITE

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Gary Braun
Project Manager

Executive Summary

Environmental stewardship is an important aspect of Lockheed Martin Corporation's commitment to the communities in which the Corporation operates. Accordingly, the Corporation has assumed responsibility for the assessment and cleanup of environmental impacts for the Lockheed West Seattle Superfund Site as part of this continuing stewardship.

This Executive Summary presents the results of the Remedial Investigation and the findings of the Feasibility Study for the Lockheed West Seattle Superfund Site (Lockheed West Site or the Site). The Remedial Investigation provides the information on the nature and extent of contamination, the risks to human health and the environment, the nature of ongoing sources of contamination, and the physical and chemical properties that influence the fate and transport of contaminants found at the Site. The results of the Remedial Investigation culminate in the identification of risks and definition of the study area boundary to be used in the Feasibility Study. Therefore, the Remedial Investigation uses the historical lease area boundaries and the Feasibility Study uses the study area boundary defined in the Remedial Investigation. The Feasibility Study contains a description and evaluation of a range of remedial alternatives for addressing the Site risks identified during the Remedial Investigation through remediation of sediment contamination at the Site and identifies a best-supported alternative for a final remedy. The investigation and study were both completed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Administrative Settlement Agreement and Order on Consent (U.S. Environmental Protection Agency [EPA] Docket No. CERCLA 10-2006-0321) and associated Statement of Work for the Site.

ES.1 SITE DESCRIPTION AND HISTORY

The Lockheed West Site represents the aquatic portions of what formerly was known as Lockheed Shipyard No. 2 located near where the West Waterway enters Elliott Bay, west of the city of Seattle, Washington (Figure ES-1). The former shipyard uplands are currently owned by

Legend

- Approximate Site Boundary: Site boundaries will be finalized in the Record of Decision.
- Highway
- Major Road
- Local Road
- RA5 - Former Shipyard Uplands
- Creek
- Railroad
- Greenbelt
- LSSOU — Lockheed Shipyard Sediment Operable Unit
- TSSOU — Todd Shipyard Sediment Operable Unit
- OU — Operable Unit

Figure ES-1 Lockheed West Site Location and Vicinity Map

0 500 1,000 Feet

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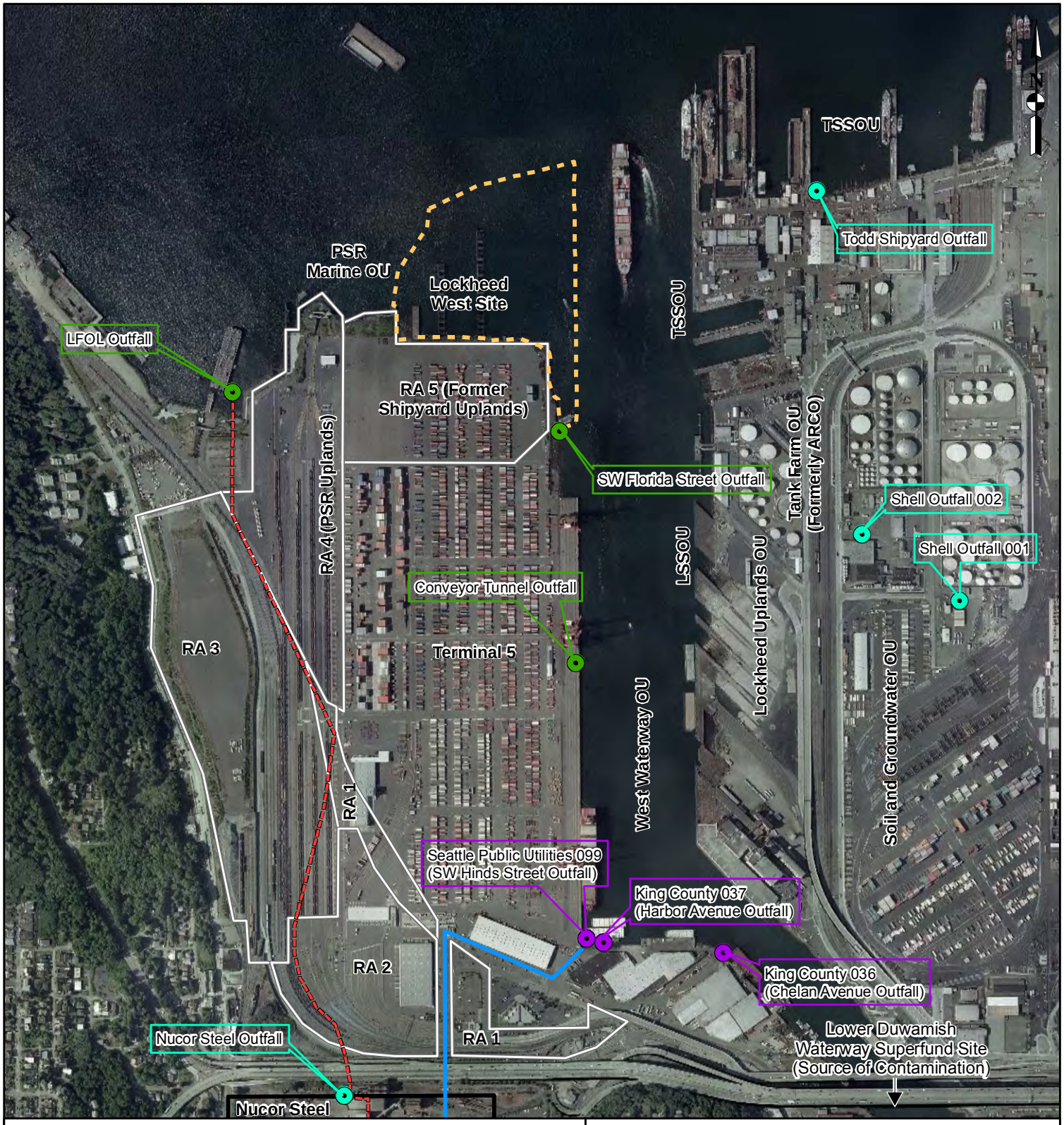
the Port of Seattle (Port) and are not included as part of the Site for this Remedial Investigation and Feasibility Study. The study area consists of the areal extent of sediment contamination associated with former shipyard operations. The Site is bordered by Elliott Bay on the north, the Harbor Island West Waterway Operable Unit on the east, Pacific Sound Resources Marine Sediment Unit on the west, and the Port of Seattle Terminal 5 to the south (Figure ES-1). The aquatic area includes approximately 7 acres that was acquired by the Port of Seattle from Lockheed Martin Corporation with the remainder consisting of aquatic state-owned land managed by the Washington State Department of Natural Resources.

The Site is located in a historically industrialized and commercial area of Seattle shown in Figure ES-2. There are several nearby environmental cleanup projects and major drainage discharges in the vicinity. The Duwamish Estuary and Elliott Bay have experienced extensive development and urban growth during the 20th century. The Duwamish Waterway is part of the larger south Seattle/Duwamish industrial district, the oldest of three industrial zones in the greater Seattle area. The district is also a major transportation corridor for rail, trucking, and waterborne shipping. The primary land uses near the Site have been industrial and maritime for over a century. Warehousing, commercial, and industrial distribution activities are located throughout the area. The adjoining area of the West Waterway includes a federally maintained navigation channel, and numerous privately maintained berthing areas.

Prior to development in the early 1900s, the Site and the area around it consisted of an intertidal deltaic environment at the mouth of the Duwamish River. Most of the pre-existing wetlands and mudflats were lost during construction of the Lower Duwamish Waterway and Harbor Island. The shoreline of the former shipyard is characterized by armoring or bulkheads with the exception of a small intertidal beach on the West Waterway. Currently, the upland areas adjacent to the Site are used by the Port of Seattle for shipping container storage. The Lower Duwamish Waterway and Elliott Bay are tribal fishing areas for the Muckleshoot and Suquamish Native American Tribes.

Beginning in 1942, the intertidal areas on the northern terminus of the current Port of Seattle Terminal 5 were dredged. At the outset of World War II, shipyard activities at the Site were operated by Puget Sound Bridge and Dredge Company, a predecessor of the Puget Sound Bridge



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RA = Southwest Harbor Remediation Area
PSR = Pacific Sound Resources
LSSOU = Lockheed Shipyard Sediment OU
TSSOU = Todd Shipyard Sediment OU
NDPES = National Pollutant Discharge Elimination System
CSO = Combined Sewer Overflow
LFOL = Longfellow Overflow Line
OU = Operable Unit

Approximate Site Boundary: Site boundaries will be finalized in the Record of Decision.
Remedial Action Areas
Longfellow Overflow Line
Longfellow Creek

Outfall Type

CSO
Other Drainage Feature
NDPES Permitted Discharge

Arial Imagery Source: United States Geological Survey 2002.

Figure ES-2 Nearby Environmental Cleanups and Major Discharge Features General Vicinity Map

0 500 1,000
Feet

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and Drydock Company, which was purchased by the Lockheed Shipbuilding and Construction Company in 1959. The Site primarily served as a ship repair, maintenance, and new ship construction facility and included five major piers, three dry docks, and a shipway. The dry docks and shipway were used to repair, sandblast, and paint vessels. Lockheed Martin Corporation discontinued the shipyard operations in 1987. The Port purchased the shipyard property in 1988.

ES.2 NATURE AND EXTENT OF CONTAMINATION

The Site remedial investigation fieldwork was conducted from 2006 through 2008. Site features and sample locations are shown in Figure ES-3. Field activities and collected data include the following:

- Performance of a high-resolution multibeam bathymetry survey, shoreline conditions survey, and topographic survey;
- Collection of surface sediment samples from the intertidal and subtidal areas;
- Collection of subsurface sediment samples from the subtidal area;
- Collection of pore water and surface water samples; and
- Performance of clam reconnaissance surveys and collection of clam tissue samples.

Analytical data from the surface and subsurface sediment samples (Table ES-1) show that metals, polychlorinated biphenyls (PCBs), tributyltin, and polycyclic aromatic hydrocarbons (PAHs) are the most frequently detected compounds in the study area.

The Washington State Sediment Management Standards (Washington Administrative Code 173-204) have been identified as applicable or relevant and appropriate requirements for evaluating sediment contamination at the Site. The Sediment Management Standards provide a basis for the management and reduction of pollutant discharges and guide contaminated sediment cleanup efforts. They include regionally developed numerical sediment criteria that protect the benthic (i.e., bottom-dwelling) invertebrate community. The benthic invertebrate numerical criteria are not intended to be protective of human health with regard to consumption of bioaccumulative contaminants in seafood. There are two levels of chemical and biological Sediment Management Standards. The more stringent level, the Sediment Quality Standards

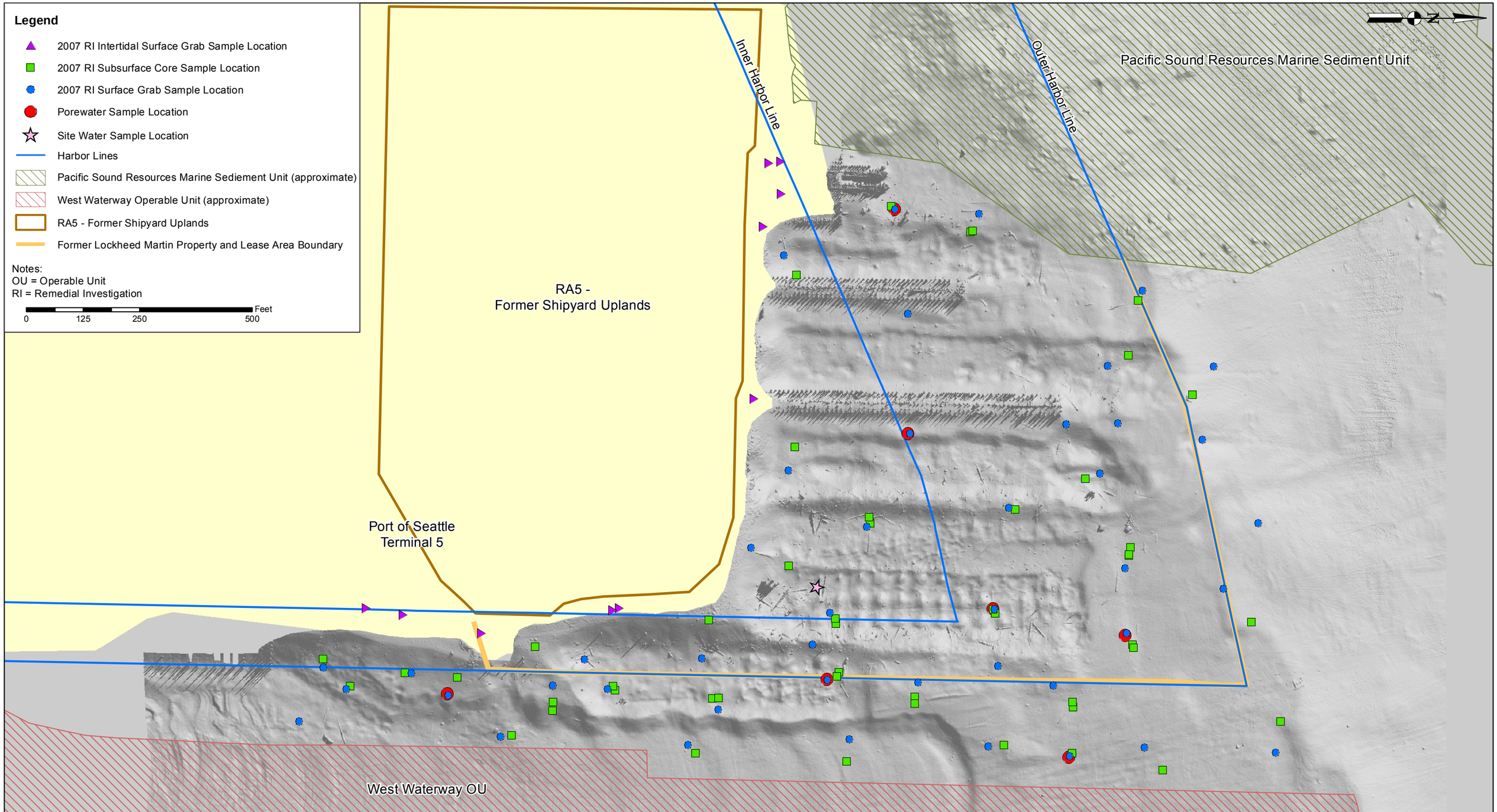
(SQS), is the sediment cleanup objective and corresponds to a sediment quality that has no acute or chronic adverse effects on benthic marine organisms. The less stringent level, the Cleanup Screening Level, is the level above which minor adverse effects are likely to occur in benthic marine organisms. The use of the Washington State SQS was adopted for screening-level comparisons in support of the investigation for the Site. The SQS represent generally accepted benchmarks; however, they do not represent the final cleanup standards for the Site.

The investigation results show that the highest concentrations of contaminants detected in the sediment at the Site are found in the former dry dock areas and in the area of the former shipway. Figure ES-4 shows the horizontal extent of surface and subsurface sediment contamination for two primary contaminants of concern: copper and total PCBs. The extent of copper contamination above the SQS is generally representative of the distribution of other metals and tributyltin, while the distribution of PCBs above the SQS screening criteria encompasses the extent of polynuclear aromatic hydrocarbons. The horizontal extent of PCB concentrations above the SQS (Figure ES-4) extends beyond the immediate areas of the dry docks and the shipway and has the greatest horizontal extent for the surficial sediments. The vertical extent of contamination was found to be deepest in the area of the former dry docks.

ES.3 SOURCE CONTROL

Understanding potential sources of recontamination to the Site is important to determine whether an implemented remedy will likely remain protective. Historical shipyard operations at the Site were discontinued in 1987. There is no current ongoing source of contamination from these historic operations; however, there are several ongoing, potential off-site sources that could represent future sources of contamination to the Site sediments.

The evaluation of ongoing contaminant sources to the Site sediments was performed as part of the Remedial Investigation. That evaluation concluded that off-site, in-water sources are potential sources of contaminants and Site sediments are expected to reach a long-term equilibration at levels above the risk-based threshold concentrations or natural background levels.



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Lockheed West Seattle Superfund Site, Seattle, WA

Figure ES-3
Lockheed West Site Vicinity

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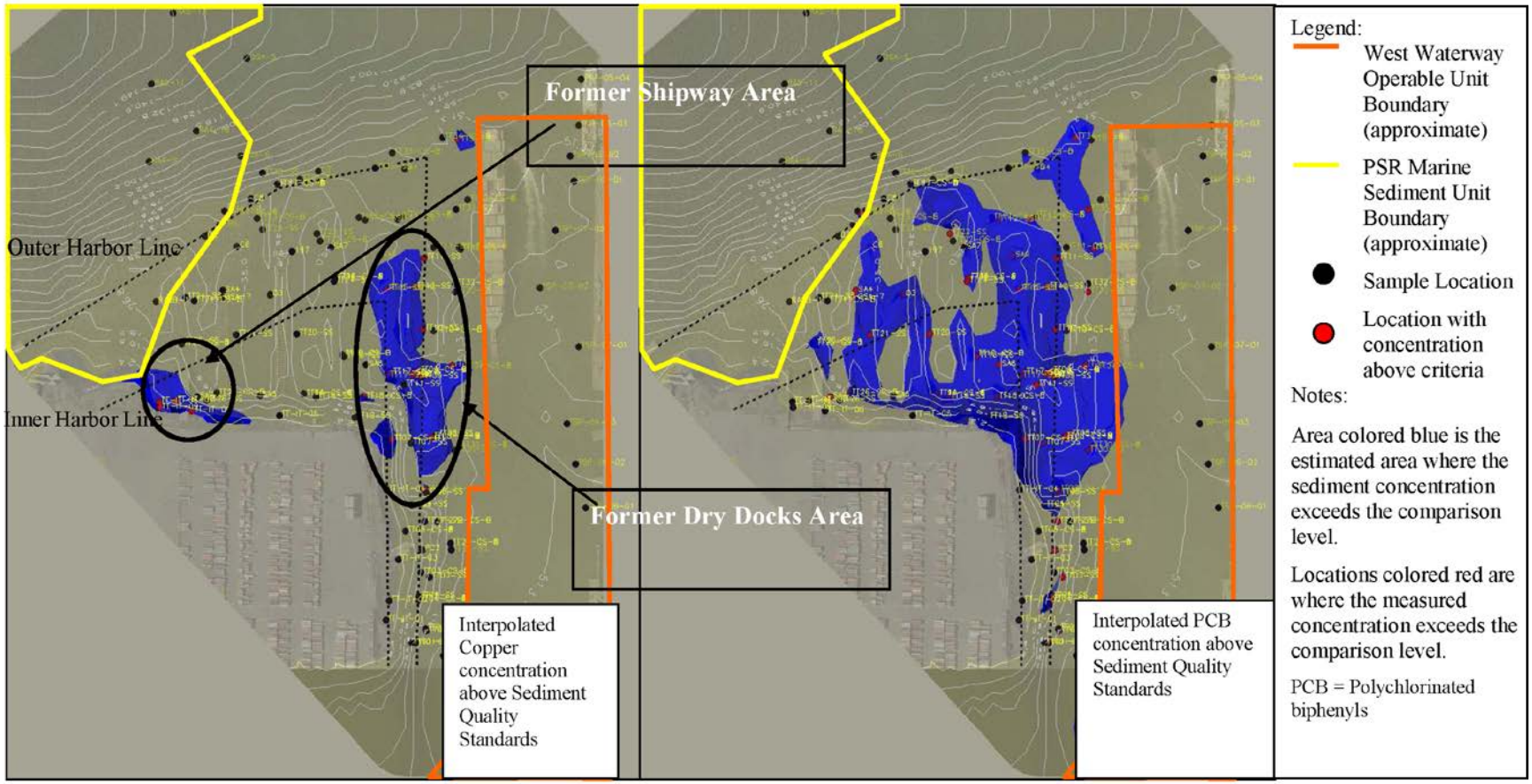
Table ES-1.
Surface and Subsurface Sediment Summary of Detected Parameters

Parameter	Detection Summary Surface Samples (Subtidal and Intertidal)			Detection Summary Subsurface Samples		
	Detection Frequency (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Detection Frequency (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)
Metals						
Antimony	100.0	0.43	194	95.6	0.043	256
Arsenic	100.0	4.56	330	100.0	1.11	374
Cadmium	100.0	0.04	1.05	100.0	0.032	2.38
Chromium	100.0	14.4	504	100.0	2.1	925
Cobalt	100.0	3.18	38.6	100.0	2.07	31.7
Copper	100.0	28.2	1900	100.0	6.7	2620
Lead	100.0	15.9	1420	100.0	1.76	2200
Mercury	100.0	0.021	2.94	95.0	0.0005	17.1
Molybdenum	100.0	0.36	23.8	100.0	0.23	21
Nickel	100.0	7.29	151	100.0	1.1	413
Selenium	64.8	0.2	1.2	73.2	0.1	1.4
Silver	100.0	0.071	1.31	91.9	0.015	1.42
Thallium	100.0	0.033	0.314	100.0	0.023	0.25
Vanadium	100.0	22	95.6	100.0	21.9	336
Zinc	100.0	47.5	1430	100.0	19.6	2680
TBT						
Tributyltin	100.0	0.00081	4.5	84.1	0.00021	9.1
PAHs						
Total HPAH	100.0	0.0288	70.7	96.8	0.0018	163.9
Total LPAH	98.6	0.0129	4.8	98.1	0.0018	107.42
PCBs						
PCBs (total)	100.0	0.0042	3	71.3	0.0041	9.62
Pesticides						
Total chlordane	57.4	0.00014	0.046	40.6	0.00016	0.2
Total DDT	96.3	0.00028	0.294	71.0	0.00014	1.02
Miscellaneous SVOC						
bis(2-ethylhexyl)phthalate	100.0	0.0032	0.89	88.0	0.0029	11
Butyl benzyl phthalate	65.8	0.0033	0.096	7.6	0.0022	0.092
Di-n-butyl phthalate	82.2	0.0035	0.069	56.3	0.0036	2.1

Notes:
Detected results include estimated concentrations below the sample reporting limits.
- = Compound was not detected for noted samples
mg/kg-dw = milligram per kilogram dry weight
HPAH = heavy weight polycyclic aromatic hydrocarbon
LPAH = light weight polycyclic aromatic hydrocarbon
PCBs = polychlorinated biphenyl
SVOC = semivolatile organic compound

Figure ES-4. Horizontal Extent of Surface and Subsurface Sediment concentrations above the Sediment Quality Standards for Copper and Total PCBs



Potential sources of remedy recontamination are outside of the control of Lockheed Martin Corporation. Of the sources evaluated during the Remedial Investigation, transport and deposition of contaminated sediment within the West Waterway and from Elliott Bay represents the highest likelihood of remedy recontamination. A review of available information shows that overwater uses and spills, wastewater discharges, combined sewer overflows, stormwater discharges, upland contaminated groundwater discharges, and atmospheric deposition are less likely to be significant sources of recontamination.

ES.4 RISK SUMMARY

The human health and ecological risk assessments identified contaminants of concern, human and ecological receptors, and the pathways for exposure that resulted in unacceptable risks to human health and the environment from the Site. For the human health risk assessment, five reasonable maximum exposure scenarios were identified: 1) children playing on the beach, 2) tribal clamming, 3) net fishing, 4) consumption of seafood by tribal adults, and 5) consumption of seafood by tribal children. The primary exposure pathways evaluated in the human health risk assessment were ingestion and direct contact. Ecological receptors of concern and pathways of exposure were identified for the ecological risk assessment as the following:

- Benthic invertebrate community including clams – Direct contact and ingestion exposure to subtidal and intertidal sediment.
- Crabs – Exposure to ingested prey and direct contact and ingestion to subtidal and intertidal sediment.
- Fish (English sole, Pacific staghorn sculpin) – Exposure of higher trophic organisms to ingested prey and direct contact and ingestion exposure to subtidal and intertidal sediment.
- Birds (Spotted sand piper) – Exposure to ingested prey and ingestion exposure to intertidal sediment.

The risk assessments included screening for contaminants of potential concern, identification of the contaminants of concern, and identification of the risk-driver contaminants that are predicted to have the highest contribution to estimated human health and ecological risks, and which are summarized in Table ES-2.

Table ES-2.
Summary of Contaminants of Concern and Risk-Driver Contaminants of Concern for Site Receptors and Exposure Pathway

Medium:	Receptor/ Scenario:	Contaminants of Potential Concern	Contaminants of Concern	Risk Driver Contaminants of Concern
Subtidal/ Intertidal Sediment	**Human Health Tribal Adult /Seafood Ingestion**	16 COPCs	9 COCs	5 Risk drivers Metals: arsenic, tributyltin Organics: cPAHs, total PCBs, dioxins/furans [1/]
	Human Health Tribal Child /Seafood Ingestion	16 COPCs	11 COCs	6 Risk drivers Metals: arsenic, lead, tributyltin Organics: cPAHs, total PCBs, dioxins/furans [1/]
Subtidal/ Intertidal Sediment	**Human Health /Direct Exposure Netfishing**	6 COPCs	3 COCs	3 Risk drivers Metals: arsenic Organics: cPAHs, dioxins/furans [1/]
Intertidal Sediment	**Human Health/ Direct Exposure Beach Play**	7 COPCs	3 COCs	3 Risk drivers Metals: arsenic Organics: cPAHs, dioxins/furans [1/]
	Human Health/ Direct Exposure Tribal Clamming	7 COPCs	2 COCs	2 Risk drivers Metals: arsenic Organics: dioxins/furans [1/]
Subtidal/ Intertidal Sediment	**Benthic Invertebrate Community**	27 COPCs	Intertidal 11 COCs above lesser criteria[2/] in at least one station Subtidal 25 COCs above lesser criteria[2/]	combined subtidal + intertidal 4 COCs above greater criteria[2/] in at least 6 percent of stations 3 Metals (arsenic, copper, mercury) Total PCBs
Subtidal/ Intertidal Sediment	**Crabs**	34 COPCs	2 COCs	1 Risk driver TBT
Subtidal/ Intertidal Sediment	**Fish**	34 COPCs	3 COCs	3 Risk drivers copper TBT total PCBs
Intertidal Sediment	**Sandpiper**	8 COPCs	2 COCs LOAEL HQ >1	2 Risk drivers, LOAEL HQ >1 copper, lead

Notes:
1/ Dioxins/furans were identified as COCs and risk drivers for seafood consumption and direct contact scenarios based on the assumption that they would be present in tissue and sediments at concentrations above regulatory risk thresholds.
2/ Lesser criteria = SQS, DMMP screening level, NOAEL, or LAET; greater criteria = CSL, DMMP maximum level, LOAEL, or 2LAET; risk drivers are identified as COCs exceeding the greater criteria in at least 6 percent of stations (i.e., in more than 3 of the 51 stations).

2LAET = second lowest apparent effects threshold
cPAH = carcinogenic polycyclic aromatic hydrocarbon
COC = contaminant of concern
COPC = contaminant of potential concern
CSL = cleanup screening level
DMMP = Dredge Material Management Program
HQ = hazard quotient
LOAEL = lowest observed adverse effects level
NOAEL = no observed adverse effects level
PCB = polychlorinated biphenyl
SQS = sediment quality standard
TBT = tributyltin

Table ES-3 summarizes risk results for the contaminants of concern. For human health risk, contaminants of concern were identified as those contaminants with an excess cancer risk estimate greater than one in one million (1×10^{-6}) for carcinogenic contaminants or with a hazard quotient greater than 1 for non-carcinogenic contaminants. For the ecological risk assessment, those contaminants with a hazard quotient greater than one were identified as contaminants of concern. In addition, dioxins and furans were identified as contaminants of concern based on their assumed presence in the sediments and seafood, and assumed cancer-risk estimates above regulatory thresholds. Risk-driver contaminants of concern were identified based on the absolute magnitude of risk and the relative contribution to total risk for a given human-health exposure scenario or ecological receptor.

Eight contaminants are identified as risk-drivers. The risk-drivers and the associated receptor and exposure scenario that drives the risk are summarized as follows:

- **Arsenic** – tribal adult and child: seafood ingestion, net fishing, beach play, clamming; benthic invertebrates.
- **Copper** – benthic invertebrates, fish, sandpiper.
- **Lead** – tribal child: seafood ingestion; sandpiper.
- **Mercury** – benthic invertebrates.
- **Tributyltin** – tribal adult and child: seafood ingestion; crabs, fish.
- **cPAHs** – tribal adult and child: seafood ingestion, netfishing, beach play.
- **Total PCBs** – tribal adult and child: seafood ingestion; benthic invertebrates, fish.
- **Dioxins/furans** – tribal adult and child: seafood ingestion, netfishing, beach play, clamming.

ES.5 FATE AND TRANSPORT

Most of the risk-driver contaminants such as total PCBs, PAHs, and metals in the sediments at the Site are hydrophobic (not readily dissolved in water) and partition (bind) to the solid phase (i.e., sediment particles) as opposed to being dissolved in the water. Suspended and bedload sediment transport appears to represent the dominant process for contaminant migration. The

Table ES-3.
Risk Estimates for Contaminants of Concern for Human Health Risk Assessment Scenarios and Ecological Receptors (Page 1 of 2)

HHRA RME Scenario	Contaminant of Concern (COC)	Cancer Risk	Hazard Quotient
Adult Tribal Seafood Consumption – Tulalip Survey	Arsenic	3×10^{-3}	5.8
	Chromium	Not COPC	1.1
	Copper	Not COPC	1.2
	Zinc	Not COPC	1.2
	TBT (as ion)	Not COPC	89
	Pentachlorophenol	3×10^{-6}	0.001
	cPAHs	3×10^{-3}	Not COPC
	Total PCBs	3×10^{-3}	72
	Total chlordane[1/]	2×10^{-5}	0.1
	Total DDTs[1/]	3×10^{-4}	1.5
	Dioxins/Furans	Not quantified	
	Total Excess Cancer Risk and Non-Cancer Hazard Index[2/]	9×10^{-3}	173
Child Tribal Seafood Consumption – Tulalip Survey	Arsenic	5×10^{-4}	12
	Cadmium	Not COPC	1.9
	Chromium	Not COPC	2.4
	Copper	Not COPC	2.6
	Mercury	Not COPC	2.2
	Zinc	Not COPC	2.6
	TBT (as ion)	Not COPC	193
	cPAHs[3/]	3×10^{-3}	Not COPC
	Total PCBs	5×10^{-4}	154
	Total chlordane[1/]	3×10^{-6}	0.22
	Total DDTs[1/]	5×10^{-5}	3.2
	Dioxins/Furans	Not quantified	
	Total Excess Cancer Risk and Non-Cancer Hazard Index[2/]	4×10^{-3}	372
Netfishing	Arsenic	3×10^{-5}	0.1
	cPAHs	3×10^{-6}	Not COPC
	Dioxins/Furans	Not quantified	
Beach Play	Arsenic	7×10^{-5}	1.8
	cPAHs	2×10^{-6}	Not COPC
	Dioxins/Furans	Not quantified	
	Total Excess Cancer Risk and Non-Cancer Hazard Index[2/]	7×10^{-5}	2.6

Table ES-3.
Risk Estimates and Contaminants of Concern for Human Health Risk Assessment Scenarios and Ecological Receptors (Page 2 of 2)

HHRA RME Scenario	Contaminant of Concern (COC)	Cancer Risk	Hazard Quotient
Clamming – 120 day/year (intertidal sediment)	Arsenic	1×10^{-4}	0.35
	Dioxins/Furans	Not quantified	
	Total Excess Cancer Risk and Non-Cancer Hazard Index[2/]	1×10^{-4}	0.5
Ecological Receptor	**Contaminant of Concern (COC)**	**NOAEL Hazard Quotient**	**LOAEL Hazard Quotient**
English sole	Copper	36	18
	Tributyltin (TBT)	158	18
	PCBs	6 - 31	1 - 6
Pacific staghorn sculpin	Copper	28	14
Crab	PCBs	9	0.9
	TBT	202	not available
Spotted sandpiper (intertidal sediment)	Chromium	6	1
	Copper	4	3
	Lead	48	14
	TBT	1	0.6
Benthic invertebrates	26 chemicals	> SMS or other criteria	

Notes:
1/ Tentatively identified chemical (JN-qualified).
2/ Total across all chemicals. This total is not directly interpretable for risk assessment, but a value greater than 1 suggests that an HQ may exceed 1 for individual endpoints.
Not COPC = not a contaminant of potential concern for that scenario, or the toxicity endpoint is not relevant, and hence cancer risk or hazard quotient not calculated.
COC = contaminant of concern, based on human health excess cancer risks > 1×10^{-6} or HQ > 1 for human health or ecological receptors.
cPAH = carcinogenic polycyclic aromatic hydrocarbon
HHRA = human health risk assessment
PCB = polychlorinated biphenyl
RME = reasonable maximum exposure
TBT = tributyltin

potential for migration of dissolved phase contaminants is relatively low. The Site is a net depositional area that is characterized by a low sedimentation rate. In the Site vicinity, there is evidence of suspended and bedload sediment transport that carries contamination for some risk-driver contaminants above background concentrations. The sediment stability analysis indicates that the bed sediments are not likely to be moved by wave action. The bathymetry survey supports the conclusion that the sediments are stable. The potential for contaminant migration off-site through the migration of sediment particles is low in part because the Site is a net depositional area. If the sediments become disturbed, for example by dredging or by propeller wash, there is a greater potential for contaminant migration; however, it would be episodic in nature (not persistent).

ES.6 REMEDIAL ACTION OBJECTIVES AND PRELIMINARY REMEDIATION GOALS

The remedial action objectives (RAOs) for the Site provide the foundation upon which preliminary remediation goals, cleanup levels, and remedial alternatives can be developed. These objectives have been developed to guide the evaluation of remedial alternatives so that they are protective of human health and ecological receptors. The step of identifying narrative RAOs translates the findings of the risk assessments into a series of objectives to be addressed in the development of remedial alternatives in the Feasibility Study. The following four objectives have been defined for the cleanup of the Lockheed West Site:

- **Remedial Action Objective 1**. *Reduce human health risks associated with the consumption of resident Lockheed West Site seafood by reducing sediment and surface water concentrations of contaminants of concern to protective levels.*

  Note: Expected improvements to surface water quality will be achieved through remediation of Site sediments; no active remediation of surface water will be conducted.

- **Remedial Action Objective 2**. *Reduce human-health risks associated with exposure to contaminants of concern through direct contact with sediments and incidental ingestion to protective levels by reducing sediment concentrations.*

- **Remedial Action Objective 3**. *Reduce risks to benthic invertebrate organisms by reducing surficial sediment concentrations of contaminants of concern to protective levels.*

- **Remedial Action Objective 4**. *Reduce risks to crabs, fish, birds, and mammals from exposure to contaminants of concern by reducing concentrations of contaminants of concern in sediment and surface water to protective levels.*

  Note: Expected improvements to surface water quality and reduction of any potential risks to fish and wildlife will be achieved through remediation of Site sediments; no active remediation of surface water will be conducted.

Preliminary remediation goals define target sediment concentrations that provide adequate protection of human health and environment and achieve the risk reductions identified for each RAO (Table ES-4). These preliminary remediation goals are applied on a point basis or across the Site on a sitewide average basis depending on the exposure pathway being addressed. The preliminary remediation goals will be evaluated by EPA and final cleanup levels will be identified in the EPA decision documents.

Numerical preliminary remediation goals for the Site have been developed based on risk-based threshold concentrations, applicable or relevant and appropriate requirements, and natural background concentrations. In developing preliminary remediation goals, the risk-based threshold concentrations are considered first, except for the following circumstances: 1) where risk-based threshold concentrations are greater than the SQS, which are applicable or relevant and appropriate requirements for the Site, then the SQS are used as the preliminary remediation goals; and 2) where the risk-based threshold concentrations are below natural background concentrations, then natural background concentrations are used as the preliminary remediation goals. For the purposes of this Feasibility Study, natural background concentrations were used as preliminary remediation goals for evaluation of RAOs 1 and 2 for those contaminants with risk-based threshold concentrations below natural background.

The key applicable or relevant and appropriate requirement that influenced the selection of numerical sediment preliminary remediation goals for the Lockheed West Site is the Washington State Sediment Management Standards (Chapter 173-204 of the Washington Administrative Code). The Sediment Management Standards provide a basis for the management and reduction of pollutant discharges and guide contaminated sediment cleanup efforts. They include regionally developed numerical sediment criteria that protect the benthic invertebrate community, which is why they apply to RAO 3.

Table ES-4. Summary of Preliminary Remediation Goals for Risk-Driver Contaminants of Concern in Lockheed West Surface Sediment

Risk Driver Contaminant of Concern	Spatial Scale of Exposure[1/]	RAO 1: Human Seafood Consumption[2/]	RAO 2: Human Direct Contact[2/]	RAO 3: Benthic Organisms[3/]	RAO 4: Ecological (Fish, Crab, Sandpiper)[4/]
Total PCBs (µg/kg dw)	Sitewide	2	n/a	n/a	100
	Intertidal	2	n/a	n/a	n/a
	Point	n/a	n/a	12 (OC)/180 (dw)	n/a
cPAHs (µg TEQ/kg dw)	Sitewide	9	550[5/]	n/a	n/a
	Intertidal	9	150[6/]	n/a	n/a
	Point	n/a	n/a	n/a[7/]	n/a
Arsenic (mg/kg dw)	Sitewide	7	7	n/a	n/a
	Intertidal	7	7	n/a	n/a
	Point	n/a	n/a	57	n/a
Lead (mg/kg dw)	Sitewide	11	n/a	n/a	n/a
	Intertidal	11[8/]	n/a	n/a	50
	Point	n/a	n/a	n/a	n/a
Tributyltin (µg/kg dw)	Sitewide	430	n/a	n/a	150
	Intertidal	2,000[8/]	n/a	n/a	n/a
	Point	n/a	n/a	n/a	n/a
Copper (mg/kg dw)	Sitewide	400	n/a	n/a	114
	Intertidal	400[8/]	n/a	n/a	420
	Point	n/a	n/a	390	n/a
Mercury (mg/kg dw)	Sitewide	0.41	n/a	n/a	n/a
	Intertidal	0.17	n/a	n/a	n/a
	Point	n/a	n/a	0.41	n/a
Dioxins/Furans (ng TEQ/kg dw)	Sitewide	2	37[9/]	n/a	n/a
	Intertidal	2	13[9/]	n/a	n/a
	Point	n/a	n/a	n/a	n/a

mg/kg dw = milligrams per kilogram dry weight
µg/kg dw = micrograms per kilogram dry weight
n/a = compounds do not present a risk for the RAO scenario.
ng TEQ/kg dw = nanograms toxicity equivalents per kilogram dry weight
ug TEQ/kg dw = micrograms Toxicity Equivalents per kilogram dry weight
OC = Organic Carbon

1/ The spatial scale of exposure is measured as sitewide (i.e., all subtidal and intertidal sediments), intertidal sediments only, and point measurements at single locations throughout the site (i.e., all subtidal and intertidal sediment locations) or at single locations in intertidal sediment only. The spatial scale is RAO-specific, with sitewide exposures applicable to human seafood consumption, human direct contact, and exposures of fish and crab. Intertidal-only exposures are applicable to human consumption of clams from intertidal areas and exposures of sandpiper. Point exposures are applicable to benthic organisms, which are evaluated at single station locations. The statistical metric for sitewide and intertidal evaluation of alternatives and compliance monitoring is the upper confidence limit on the mean, whereas point exposures are evaluated with concentration data at single locations.

2/ PRGs are based on 10-6 cancer risk for carcinogens (e.g., PCBs, cPAHs, arsenic) or on a child exposure hazard quotient of 1 for non-carcinogens (lead, tributyltin, copper). Where PRGs based on carcinogenic risks are below background, the background concentration is selected.

3/ Applicable on a point exposure only. Values shown for PCBs are the organic carbon-normalized SQS and the dry weight equivalent based on an average sediment TOC content of 1.5%; for all other compounds values are dry weight. Under the SMS, sediment cleanup standards are established on a site-specific basis within an allowable range. The SQS and CSL define this range. For chemicals without SMS, LAET and 2LAET values or the SL and ML of the DMMP define this range. For this FS, the PRG has been set at the lowest end of the ranges. However, the final cleanup standard will be set in consideration of the net environmental effects, cost, and technical feasibility of different cleanup alternatives.

4/ PRGs for sitewide exposure are the lowest for either fish or crab; PRGs for intertidal exposure are for sandpiper.

5/ The PRG for sitewide direct contact is based on netfishing.

6/ The PRG for intertidal direct contact is based on the lowest for either tribal clamming or child beach play exposures.

7/ Low- and high-molecular weight PAHs are addressed by SMS criteria, set for groups of PAHs and for individual compounds.

8/ The PRG for intertidal seafood consumption is based on consumption of clams from the intertidal sediment.

9/ PRGs based on values presented in the Draft Final FS for the Lower Duwamish Waterway (AECOM, 2010) site-wide and tribal clamming (intertidal)

Risk-Based Threshold Concentrations. Risk-based sediment cleanup levels that may be identified in the Record of Decision for the Site will be derived from concentrations in sediment defined as acceptable for the primary exposure pathways of greatest risks, in accordance with EPA guidance. These risk-based concentrations are termed risk-based threshold concentrations and form the basis for setting risk-based cleanup levels for Site sediment.

For human health, risk-based threshold concentrations were developed for direct sediment exposures and indirect exposures from seafood consumption. The risk-based threshold concentrations for direct sediment exposures were developed from three scenarios: 1) tribal clamming for intertidal sediment, 2) children playing on the beach for intertidal sediment, and 3) tribal netfishing for subtidal and intertidal sediment.

The preliminary remediation goals for benthic invertebrates consist of the Washington State SQS (or other criteria that serve as surrogates where SQS are unavailable). Because they are toxicity-based values, the benthic invertebrate criteria also can be considered risk-based threshold concentrations. For fish and crab, risk-based threshold concentrations are based on concentrations in sediment associated with the lowest observed adverse effects level–based hazard quotient greater than 1. The risk-based threshold concentrations for sandpiper are also based on a lowest observed adverse effects level–based hazard quotient greater than one, but are specific to ingestion of intertidal sediment during foraging, plus doses related to concentrations of contaminants in benthic invertebrates ingested as prey items.

Background Concentrations. The process in both the Comprehensive Environmental Response, Compensation, and Liability Act and the Model Toxics Control Act incorporates background concentrations for formulating preliminary remediation goals and cleanup levels. The Model Toxic Control Act defines natural background as the cleanup standard required for final remedies when natural background concentrations are higher than the calculated risk-based cleanup levels. Under this Act, a remedy that cannot achieve natural background concentrations is not considered final. The EPA has determined that this aspect of the Model Toxic Control Act is an applicable and relevant and appropriate requirement under CERCLA.

The use of natural background concentrations as a sediment cleanup level for selected contaminants of concern such as PCBs, cPAHs, lead, and arsenic is problematic in this industrial

setting because it is impractical to achieve these levels. This is because sediment concentrations for these contaminants of concern exceed natural background levels throughout the Duwamish Waterway, Harbor Island Area, and southern end of Elliott Bay, which surround the Lockheed West Site. The concentrations in these areas may be considered as anthropogenic background levels, meaning they are influenced by human activities rather than naturally occurring background levels. Concentrations of contaminants of concern in clean sediment at the Lockheed West Site would likely increase to levels similar to those in surrounding areas. For this reason, EPA Superfund and sediment cleanup guidance do not support adoption of cleanup levels below anthropogenic background in industrial settings. There is also a high probability of remedy recontamination at these very low concentrations.

A range of potential PRGs were evaluated based on both natural and anthropogenic background for the evaluation of the Lockheed West Site remedial alternatives. In the development and selection of PRGs, the following sources of background concentration data were considered (the final PRGs are presented in Table ES-4).

Natural Background Values – Natural background values are identified as sources of preliminary remediation goals for the Site. Comments from EPA on the nature and extent summary memorandum for the Lockheed West Site identified the recent EPA *Bold* survey ("Bold Study")[1] as an appropriate source for natural background levels of contaminants. The "Bold Study" is used herein as a source of natural background values for Lockheed West Site chemical contaminants.

Anthropogenic Background Values – Under the Urban Waters Initiative, Ecology[2] collected data on sediment contaminant concentrations in three anthropogenic-use/geomorphological areas of Elliott Bay: deep basin, urban/mid-bay, and harbor/inner bay. The 95 upper confidence level values from the urban/mid-bay data set were used to represent anthropogenic background along the northern and eastern borders of the Site along Elliott Bay and the West Waterway. In support

[1] U.S. Environmental Protection Agency. 2009. Data Summaries of Dioxin/Furan Congeners, PCB Aroclors, PCB Congeners, Total Organic Carbon, Grain Size, and Pesticides. Puget Sound Dioxin/PCB Survey, OSV *Bold*, 2008. January 21.
[2] Washington Department of Ecology. 2009. Urban Waters Initiative, 2007. Sediment Quality in Elliott Bay. Publication No. 09-03-014. September.

of the Remedial Investigation, other background data sets were evaluated; however, the Elliott Bay Urban values were carried forward into the Feasibility Study.

ES.7 REMEDIAL ACTION LEVELS AND AREA OF POTENTIAL ACTIONS

In the EPA Record of Decision documents, cleanup levels will be established for the list of contaminants of concern identified in the human health and ecological risk assessments. The remedial action levels are contaminant-specific sediment concentrations that trigger the need for active remediation. In this Feasibility Study, four sets of remedial action levels were used in the development of the remedial alternatives, as follows: 1) Washington State Sediment Cleanup Screening Levels; 2) Washington State Sediment Quality Standards in surface sediments; 3) Elliott Bay Urban concentrations; and 4) risk-based threshold concentration or natural background concentrations.

The selected remedial action levels are designed to address the project-specific remedial action objectives and have been used to determine the type and extent of remedial actions (i.e., dredge, isolation cap, or enhanced natural recovery) taken in each alternative. Remedial action levels were developed for each risk-driver contaminant based on the understanding that remediation to address these contaminants will also address other contaminants of concern.

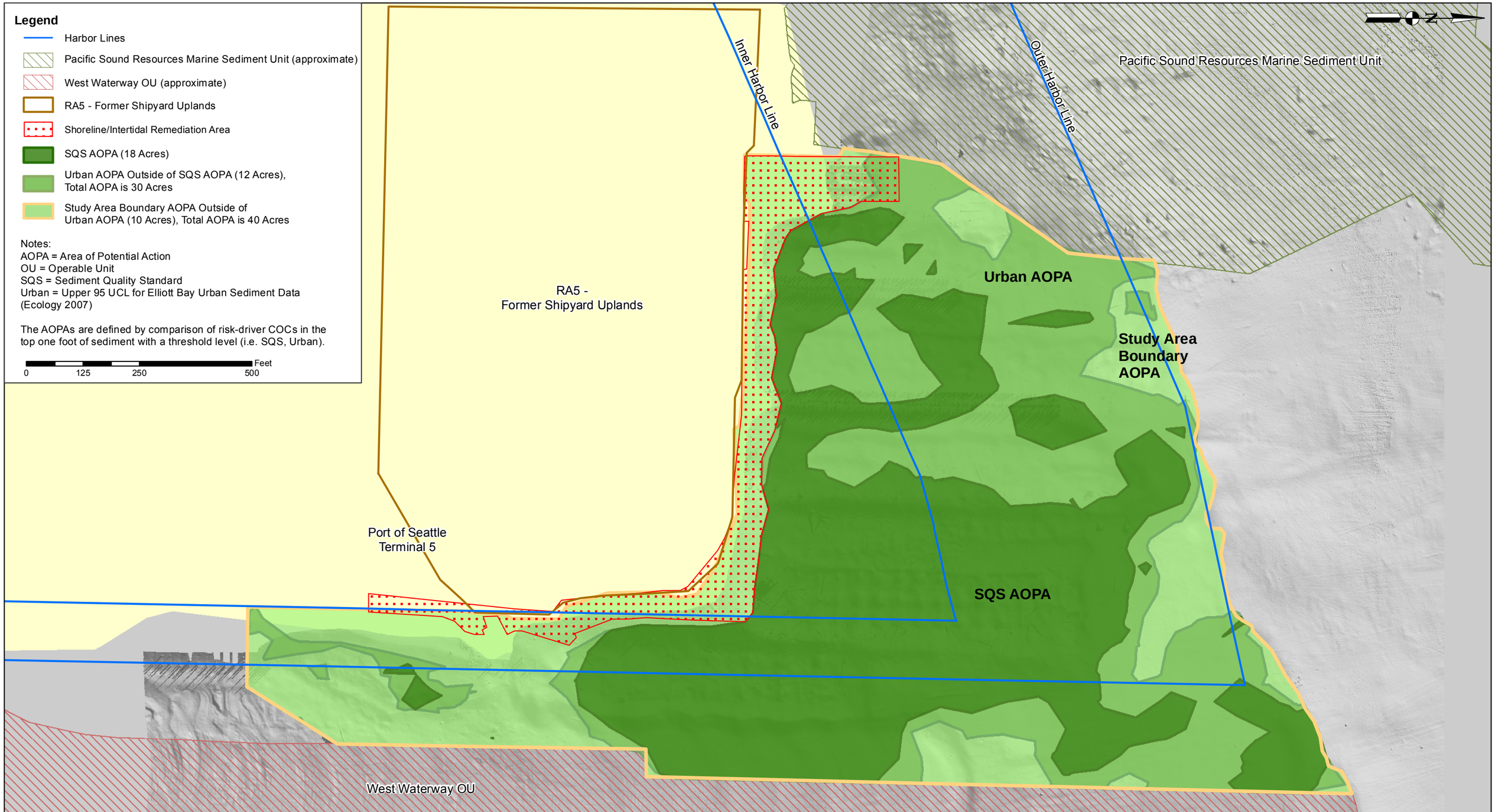
In developing remedial alternatives, the area of the remedial footprint (the area in which potential remedial actions will be taken) also was developed based on remedial action level exceedances. For the Lockheed West Site, three areas of potential action have been defined, as follows: 1) the area that exceeds Washington State Sediment Quality Standards; 2) the area that exceeds Elliott Bay Urban background levels; and 3) the study area boundary, which exceeds the natural background concentrations or risk-based threshold concentrations (Figure ES-5).

The SQS area is defined by the extent of surface sediment in the subtidal area where the concentrations for the risk-driver contaminants are above the SQS levels. This area represents the sediment that presents a risk to benthic organisms based on the SQS levels or a risk to other receptors. The SQS footprint is shown in Figure ES-5 and has an area of about 18 acres. The sediments within this area will require some type of remedial action to achieve the PRGs for RAOs 2, 3, and 4. Remedial actions implemented within this area will also address RAO 1 and achieve the PRGs to some extent; however, they will generally not completely achieve PRGs

associated with RAO 1 because areas of the Site outside of the SQS footprint, characterized by concentrations at levels comparable to the Elliott Bay Urban levels but above the natural background based PRGs, would have no action taken.

The Elliott Bay Urban area is defined by the extent of surface sediment in the subtidal area where the concentrations for the risk-driver contaminants are above the anthropogenic background RALs (as defined by samples collected by the Washington Department of Ecology in 2007 in Elliott Bay). Active remediation within this area would leave a surface-wide average concentration of risk-driver contaminants for the Site at or below the sediment conditions for the surrounding Elliott Bay area. The implementation of remedial actions within this area will achieve PRGs associated with RAOs 2, 3, and 4 and will also address RAO 1 and achieve PRGs to some extent; however, they will generally not completely achieve PRGs associated with RAO 1 because areas of the Site outside of the Urban footprint where no action would be taken will have concentrations at or below the Elliot Bay Urban levels but above the natural background–based PRGs. Over the long term, the surface and near surface sediments will reach an equilibrium concentration through mixing and the deposition of new sediment over the post-construction surface. The long-term sediment concentrations for contaminants of concern at the Site are expected to fall between the natural background levels and the concentrations found in the Elliott Bay region. The Urban footprint is shown in Figure ES-5 and has an area of about 30 acres.

The study area boundary is the third area of potential action and is defined by the administrative boundaries that exist for the Site (Figure ES-5). Implementing active remediation to the study area boundary would have the goal of reducing concentrations to natural background or risk-based threshold concentrations, and would result in sitewide average risk-driver contaminant concentrations for the surface sediments below the sediment conditions for the surrounding Elliott Bay–wide area. Implementing an active remediation to the study area boundary would result in a clean surface across the area evaluated in the Feasibility Study at the end of construction. However, in the long term, the sitewide average concentrations for the surface sediments will reach an equilibrium concentration through mixing and the deposition of new sediment over the post-construction surface. The long-term sediment concentrations for



TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure ES-5
Areas of Potential Action

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contaminants of concern at the Site are expected to fall between the natural background levels and the concentrations found in the Elliott Bay region. Action taken within this footprint would achieve the maximum level of risk reduction and achievement of the RAOs at the end of construction. The study area boundary footprint is shown in Figure ES-5 and has an area of about 40 acres.

ES.8 EVALUATION AND SCREENING OF TECHNOLOGIES

The Feasibility Study process includes identification of general response actions and associated remedial technologies and process options that were considered for development of remedial action alternatives. The technologies were screened based on effectiveness, implementability, and relative cost.

Representative technologies retained after screening are incorporated into the remedial alternatives. Additional technologies also were identified that may be considered during remedial design. Remedial technologies and process options retained for consideration in the Feasibility Study and future remedial design are summarized in Table ES-5. These technologies have been widely used in the Puget Sound region and nationally at other contaminated sediment sites. The retained technologies incorporated into the remedial action alternatives include the following:

- Removal of contaminated sediments by dredging and excavation, with disposal of the dredged material by dewatering, material transport by barge, rail, and trucks, and off-site disposal at a permitted solid waste disposal facility;
- Enhanced natural recovery, which uses a thin-layer placement of materials such as sand to enhance natural recovery processes of sedimentation to reduce surface sediment contaminant concentrations;
- Containment technologies such as conventional isolation using engineered layers of sand, gravel, or rock; and
- Institutional controls, such as seafood consumption advisories, public outreach and education designed to increase seafood consumers' awareness of risks to reduce unacceptable exposures, and restrictions on waterway use activities such as dredging or anchoring in specified areas.

Table ES-5.
Retained Remedial Technology and Process Options for the Lockheed West Site Sediment Remediation Project

General Response Action	Technology Type	Process Option
Institutional Controls	Governmental Controls	Monitoring and Notification of Waterway Users
	Proprietary Controls	Deed Restriction
	Enforcement and Permit Tools	Permits, Consent Decrees
	Informational Devices	Education and Public Outreach, Seafood Consumption Advisories, Site Registry
Monitored Natural Recovery	Physical Transport, Chemical and Biological Degradation, Physical-Burial Processes	Biodegradation, Sedimentation, Bioturbation
Enhanced Natural Recovery	Enhanced Physical Burial	Thin-Layer Placement
Containment	*In Situ* Capping	Conventional Capping
		Composite Capping
		Reactive Capping
Removal	Dredging	Mechanical Dredging
		Hydraulic Dredging
		Specialty Dredging
	Excavation	Excavator
	Passive Dewatering	On-barge
		Bermed Stockpile
		Geotubes
	Transportation	Vehicle Transport
		Rail Transport
		Water Transport
Disposal/Reuse	On-Site Disposal of Dredge Material	Confined Disposal Facility
		Confined Aquatic Disposal Facility
	Off-Site Disposal of Dredge Material	Off-Site Disposal at a Permitted Solid Waste Disposal Facility
		Off-Site Disposal at a Landfill Permitted to Accept Washington State only Dangerous Waste
		Off-Site Disposal at a Hazardous Waste Landfill
		Off-Site Disposal at a Toxic Substances Control Act Landfill
	Beneficial Reuse	In-Water Beneficial Reuse

ES.9 DEVELOPMENT OF REMEDIAL ALTERNATIVES

The remedial alternatives evaluated in this Feasibility Study comprise a combination of remedial technologies intended to achieve the preliminary remediation goals associated with the RAOs at completion of the remedial construction. The alternatives differ in the remedial action levels applied, the rate at which sediment contaminant concentrations are reduced, and the type and scale of technologies used.

The remedial alternatives were assembled by combining one or more of the retained remedial technologies and process options (Table ES-5). Each active alternative was further divided into subalternatives based on a range of areas of potential action and remedial action levels to identify which areas and to what depths sediment would be subject to active cleanup. The evaluated remedial alternatives include the No Action alternative, as well as a range of containment- and removal-focus alternatives giving a total of 16 subalternatives. Late in the review process and following EPA comments on the draft Remedial Investigation/Feasibility Study document, EPA requested consideration of several variations to the alternatives. In response to EPA's request, a technical memorandum addressing three alternative variations was prepared and is included as Appendix I to this document. Local conditions (e.g., sediment transport, chemical characteristics, and habitat) and land use considerations were also considered in the development of alternatives. All active remedial alternatives have common elements, which include the remediation of former shipway area, shoreline and intertidal habitat remediation and improvements, institutional controls, and long-term monitoring to verify achievement of project remedial action objectives.

A summary of the remedial alternatives is provided in Table ES-6. Performance summary, scope, technology application summary (e.g., cap and dredge acreage) and costs of the alternatives are presented in Table ES-7. This table also contains a description of the various subalternatives according to the area of potential action footprint and the remedial action levels applied. The evaluated remedial alternatives are summarized below.

Table ES-6.
Lockheed West Remedial Alternatives and Remedial Action Levels

Remedial Alternatives[1/]	Brief Description and Expected Outcomes	RAL Basis
Alternative 1 - No Action	CERCLA baseline alternative used for comparison to other alternatives.	None
Alternative 2 - Containment Focus	This alternative focuses on containment (capping/ENR). Common elements for this alternative include removal of debris in all areas that would prohibit cap placement /effectiveness, installing a 3-ft cap in high concentration areas /ENR (6-in sand layer) in low concentration areas[b/] to a specific surface sediment RAL footprint; leaving pier structures in place, enhance intertidal habitat, and institutional controls/restrictive covenants on site use to protect cap.	
Alternative 2A (2A1, 2A2a, 2A2b, 2A3, 2A4a, 2A4b, and 2A4c)	Cap/ENR surface sediments based on varying AOPA footprints (e.g., SQS, Urban, Study area boundary)	SQS (2A1, 2A4a) Urban (2A2a, 2A2b, 2A4b) RBTC/Nat.Bkd (2A3/2A4c)
Alternative 2B - Containment Focus with Removal – minimize changes to water depth.	Similar to Alt 2A3, cap/ENR surface sediments based on study area boundary AOPA footprint but includes removal of sediments to minimize changes to water depths. This subalternative would also include removing pier structures within areas to be dredged to fit cap, if necessary.	RBTC/Nat.Bkd (2B)
Alternative 3 - Removal Focus	This alternative focuses on removing high concentration materials in surface sediments then capping/ENR the removal area and the remainder of the Site. Common elements for this alternative include dredging high concentration sediment areas, dispose of dredged sediment at upland disposal facility, remove pier structures within the dredge areas, remove debris in all areas that would prohibit cap placement /effectiveness, 3-ft cap in remaining high concentration areas /ENR (6-in sand layer) low concentration areas[2/] containing exceedances of a specific RAL, enhance intertidal habitat, institutional controls/restrictive covenants on site use to protect cap.	
Alternative 3A – Removal Focus – remove 3 feet over CSL (3A1) or SQS (3A2) surface sediment footprint.	This combined removal and containment alternative is included to address mass removal of the most impacted sediments and is not bounded by former operational areas. The dredged area would be capped/ENR along with other areas to the Urban AOPA footprint.	3A1 - CSL 3A2 - SQS
Alternative 3B – Removal Focus – remove high concentration materials to CSL in Dry Dock 1 area.	This combined removal and containment alternative addresses the area with the greatest concentrations of COCs. The dredged area would be capped/ENR along with other areas to the Urban AOPA footprint. Removal of contaminated sediments within this area is also consistent with and would not preclude, potential future site uses in this part of the waterway.	CSL
Alternative 3C– Removal Focus – remove high concentration materials to CSL in Dry Dock areas.	This combined removal and containment alternative expands on the removal of COCs to include the area associated with former Dry Docks #1, 2, and 3. It addresses the areas with the greatest concentrations of COCs. The dredged area would be capped/ENR along with other areas to the Urban AOPA footprint. Focusing the removal of COCs on the former dry dock areas will address the portions of the site where sand-blast grit and other waste materials typical of historic ship building activities are present.	CSL
Alternative 4 – Complete Removal	This alternative is based solely on removal; no capping would be implemented in areas within the removal area or outside the removal area footprint. Common elements include removal of pier structures within the dredge areas, dredging sediments exceeding RAL criteria, dispose of dredged sediment at upland disposal facility, managing dredge residuals as necessary, and enhancing intertidal habitat.	
Alternative 4A – SQS AOPA	Removal to the SQS footprint.	SQS
Alternative 4B – Anthropogenic (Urban) AOPA	Removal to the Urban footprint.	Urban
Alternative 4C – Study Area Boundary AOPA	Removal to the Study Area Boundary.	RBTC/Nat.Bkd.

Notes:
1/ Alternatives 2 through 4 include shoreline remediation/enhancement, limited removal and capping of the former shipway area, institutional controls and long-term monitoring to verify achievement of RAOs.
2/ For containment RAL footprint: Conventional cap is assumed for areas > 2xSQS and ENR is assumed for areas < 2xSQS.
AOPA = area of potential action; CSL = cleanup screening level; ENR = enhanced natural recovery; Nat. Bkd = natural background; RALs =Remedial Action Levels; RAOs = Remedial Action Objectives; RBTCs = Risk-based Threshold Concnetrations; SQS = Sediment Quality Standard; Urban = Anthropogenic background value is 95 UCL on the mean data reported in Ecology (2008) for the "urban" stations.

Table ES-7. Lockheed West Site Remedial Alternatives - Scope, Costs, and Performance Summaries

		Alternative 1	Alternative 2								Alternative 3				Alternative 4		
		1	2A1	2A2a	2A2b	2A3	2A4a	2A4b	2A4c	2B	3A1	3A2	3B	3C	4A	4B	4C
Technology Application Summary																	
Actively Remediated Area (Acre)[1/]	Dredge	0	0	0	0	0	0	0	0	10.3	10.3	18	4	10.3	18	30	40
	Cap	0	10.3	10.3	18	10.3	18	30	40	10.3	5.4	5.4	6.3	1.3	0	0	0
	ENR	0	7.7	19.7	12	29.7	0	0	0	29.7	19.7	12	19.7	18.4	0	0	0
Former Shipway/Shoreline Remediation Area (Acre)		0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Total Actively Remediated Area[2/]		0	20	32	32	40	20	32	40	40	32	32	32	32	20	32	40
Dredge Volume (1,000 cy)[3/]		0	0	0	0	0	0	0	0	52	56	123	90	149	342	802.5	1,214
Former Shipway/Shoreline Dredge Volume (1,000 cy)		0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Construction Time (years)[4/]		0	1	1	1	1	1	1	1	1	1	1	1	1 to 2	2 to 3	5 to 6	8 to 9
Cost Summary																	
Cost (MM$)[5/]	Capital	0	11.0	12.7	15.8	14.1	14.0	20.3	25.7	27.4	24.8	43.4	33.0	44.5	92.0	203.8	302.8
	ICs, OM&M	0	6.0	6.1	9.2	6.1	8.4	13.7	18.1	5.8	4.1	4.0	4.4	2.4	0.3	0.3	0.0
	Total Cost	0	17.0	18.7	25.0	20.2	22.4	34.1	43.8	33.3	28.9	47.5	37.5	47.0	92.3	204.0	302.8
Performance Summary - RAO 1																	
RAO 1 - Human Seafood Consumption	**COCs**	**Performance Towards Reaching RAO 1 PRGs (%)[6/]**															
	Total PCBs	0	77	85	90	87	83	97	100	90	87	87	88	88	89	92	100
	Arsenic	0	93	100	100	100	99	100	100	100	100	100	100	100	100	100	100
	Copper	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Lead	0	87	94	99	96	92	100	100	97	94	94	93	93	90	100	100
	cPAHs	0	76	80	91	79	86	96	100	89	87	86	76	81	89	88	100
	TBT	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Average	17	89	93	97	94	93	99	100	96	95	94	93	94	95	97	100
Performance Summary - RAO 2, 3, 4		**Risk Threshold Achieved**															
RAO 2 - Human Direct Contact		n/a	$\leq 1x10^{-5}$ [7/]	Cumulative ($\leq 1x10^{-5}$)							Cumulative ($\leq 1x10^{-5}$)				Cumulative ($\leq 1x10^{-5}$)		
RAO 3 - Benthic Organisms		n/a	SQS	SQS							SQS				SQS		
RAO 4 - Ecological		n/a	HQ<1 [8/]	HQ<1							HQ<1				HQ<1		

Notes:

1/ Actively remediated area do not include shipway, shoreline, intertidal habitat remediation area.

2/ Total actively remediated area includes 2 acres for shipway,shoreline, intertidal habitat remediation areas, and site-wide institutional controls.

3/ The performance dredge volume is the neat dredge volume increased by 50%.

4/ One construction year is assumed as 180 days. See Appendix F for estimated number of construction days for each alternative.

5/ See Appendix F for detailed cost estimates.

6/ Based on calculated mean residual site-wide surface sediment concentrations (see Table 12-3).

7/ Alternative 2A1 and 2A4a achieve cumulative direct contact risk of $1x10^{-5}$ in sitewide and intertidal areas but PRG for arsenic not achieved (see Table 12-3).

8/ PRG for total PCBs not achieved; average of COC HQ < 1 (see Table 12-3).

cPAH = Carcinogenic Polycyclic Aromatic Hydrocarbon; cy = cubic yard; ENR = Enhanced Natural Recovery; HQ = Hazard Quotient; ICs = Institutional Controls; MM = Millions; OM&M = Operation, Maintenance, Monitoring; n/a = not achieved; PCB = Polychlorinated Biphenyl; RAO = Remedial Action Objective; SQS = Sediment Quality Standard; TBT = Tributyltin.

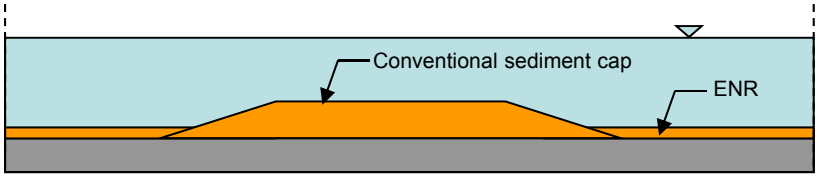
Alternative 1 – No Action. No Action denotes no cleanup actions taken or institutional controls implemented. This alternative provides a baseline for comparison with the other remedial alternatives; its inclusion is required by the Comprehensive Environmental Response, Compensation, and Liability Act.

Alternative 2 – Containment-Focus. Containment-focus alternatives address all remedial action levels within the SQS, Elliot Bay Urban, and study area boundary footprints by applying active remedial technologies of conventional isolation capping and enhanced natural recovery, and removal associated with the shipway and shoreline remediation. This general alternative includes nine subalternatives (2A1, 2A2a, 2A2a Plus 2A2b, 2A3, 2A4a, 2A4b, 2A4c, and 2B) and would actively remediate about 18 to 40 acres, depending upon the action taken. This remedy alternative is designed to achieve RAO 1 (protection of human health through seafood consumption) through a combination of active remediation and institutional controls; achieve the PRGs for RAO 2 (protection of human health by direct contact) and RAO 4 (protection of ecological health through seafood consumption) on a sitewide average basis; and the PRGs (i.e., SQS) for RAO 3 (protection of benthic community) on a point basis immediately following construction, and be protective of human health and the environment immediately upon completion.

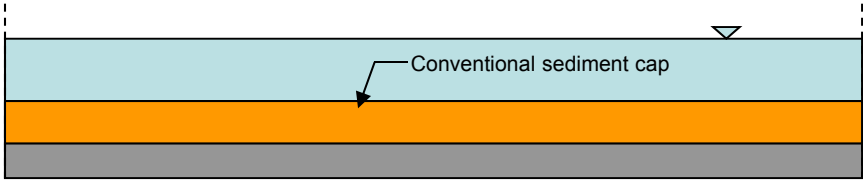
Conceptual cross-sections of the containment-focus alternatives are shown in Figure ES-6. Alternatives that result in a similar cross-section are grouped together, even though the extent of a remedial technology may vary. The containment-focus alternatives are represented by three of the conceptual cross-sections in Figure ES-6.

Alternative 3 – Removal-Focus. Removal-focus alternatives address remedial action levels within the specified area of potential action through a combination of dredging, capping, and enhanced natural recovery. The most impacted sediments will be dredged and disposed of off-site, at a licensed and permitted disposal site, and risk-driver contaminants of concern in removal areas and in all remaining areas where the concentrations are greater than remedial action levels will be contained by conventional cap or enhanced natural recovery. This general alternative includes six subalternatives (3A1, 3A2, 3A2 Plus, 3B, 3C, and 3C Plus) and active remediation of about 30 acres. This remedy alternative is designed to have some contaminant mass removal

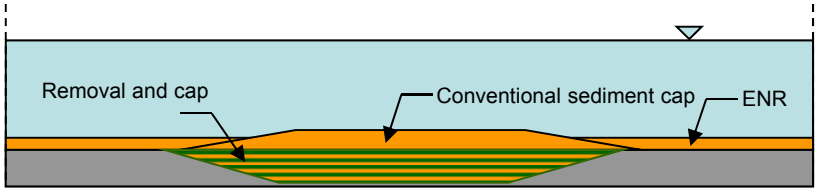
Figure ES-6. Conceptual Cross-Sections for the Lockheed West Site Alternatives



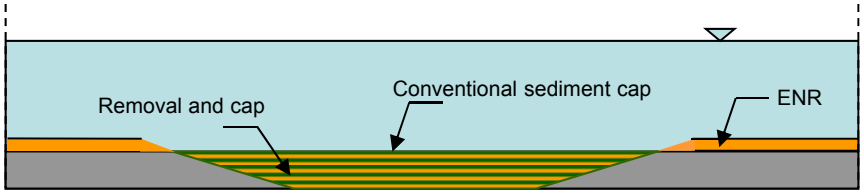
Containment-focus - Cap and ENR (Alternatives 2A1, 2A2a, 2A2b, 2A3)



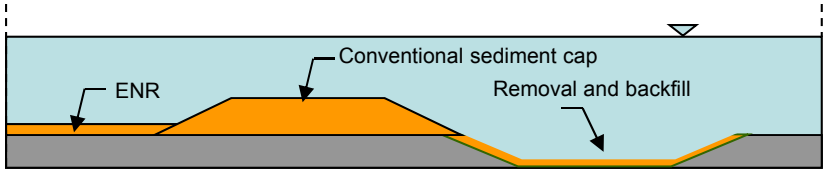
Containment-focus – Cap (Alternatives 2A4a, 2A4b, 2A4c)



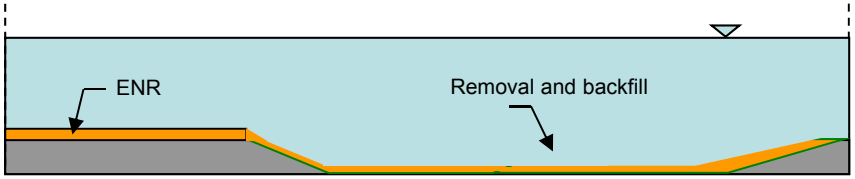
Containment-focus – Removal to minimize changes to water depth, cap and ENR (Alternative 2B)



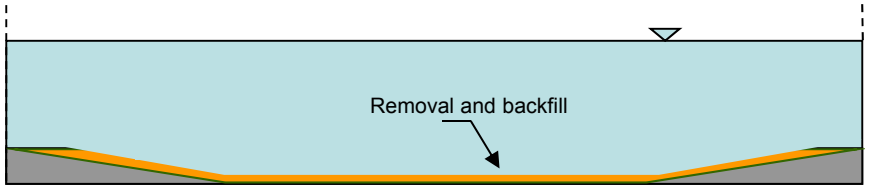
Removal-focus – Remove 3 feet, cap and ENR (Alternatives 3A1, 3A2)



Removal-focus – Removal in Dry Dock 1, cap and ENR (Alternative 3B)



Removal-focus – Removal in Dry Dock Areas, cap and ENR (Alternative 3C)



Complete Removal – Alternatives 4A, 4B, 4C

ENR = Enhanced Natural Recovery

(between 38 and 91 metric tons, depending on the alternative) and to achieve RAO 1 through a combination of active remediation and institutional controls, achieve the PRGs for RAOs 2 and 4 on a sitewide average basis and the PRGs (i.e., SQS) for RAO 3 on a point basis immediately following construction, and be protective of human health and the environment immediately upon completion.

Conceptual cross-sections of the removal focus alternatives are shown in Figure ES-6. The removal-focus alternatives are also represented by three of the conceptual cross-sections.

Alternative 4 – Complete Removal. Under the complete removal alternative, sediments within the Site where risk-driver contaminants of concern concentrations are greater than remedial action levels within the remedial footprints will be dredged and disposed of off-site. The complete removal alternative includes three subalternatives (4A, 4B, and 4C) and would incorporate active remediation of about 18, 30, or 40 acres depending on the remedial footprint. This remedy alternative is designed to achieve maximum contaminant mass removal (of between 137 and 195 metric tons, depending on the remedial footprint) compared to the other alternatives and to achieve RAO 1 through a combination of active remediation and institutional controls, achieve the PRGs for RAOs 2 and 4 on a sitewide average basis and the PRGs (i.e., SQS) for RAO 3 on a point basis immediately following construction, and be protective of human health and the environment immediately upon completion.

A conceptual cross-section of the complete removal alternatives is shown in Figure ES-6. All three complete removal alternatives result in a similar cross-section but vary in the extent of remedial action area.

ES.10 DETAILED EVALUATION AND COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

The alternatives were evaluated in detail and compared against the two thresholds and five primary balancing CERCLA criteria. Under this Act, each alternative must meet the two threshold criteria: 1) overall protectiveness of human health and the environment and 2) compliance with applicable or relevant and appropriate requirements of pertinent environmental laws and regulations to be eligible for selection as the preferred alternative. Primary balancing criteria that the alternatives are compared with include long-term effectiveness and permanence;

reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. Evaluation of the two modifying criteria—state acceptance and community acceptance—will be evaluated by the EPA after consideration of formal public comments on the proposed plan.

The detailed evaluation and comparative analysis of all alternatives for each CERCLA criterion is summarized in the following report and Table ES-8. The first several rows of Table ES-8 summarize the performance of the remedial alternatives in achieving the threshold criteria. The rest of the table presents the summary of the detailed evaluations for the balancing criteria. Alternatives 2A2a, 3A2, and 3C serve as base alternatives for the EPA-requested Feasibility Study alternative variations 2A2a Plus, 3A2 Plus, and 3C Plus. The comparative analyses for these alternative variations is provided in Appendix I.

A comparative rankings analysis also was performed to evaluate the relative overall ranking of each remedial alternative. This relative ranking was used to distinguish more thoroughly the similarities and dissimilarities among the alternatives. The general methodology for the comparative analysis rankings can be found in the following report; a summary is presented in Table ES-9, and the results of the benefits ranking analysis are graphed in Figure ES-7. Individual metrics were developed for the ranking criteria in Table ES-9 based on a zero to 10 rating scale. The rating scale is a linear relationship, with a minimum performance given a rating of zero and the maximum performance with full achievement given a rating of 10. Each of the CERCLA evaluation criteria are represented by one or more individual metrics. When a criterion has multiple metrics, the individual metric ratings were averaged to give an overall rating for the criterion. After calculating an average for each criterion, an overall score was calculated to use for the overall comparison. The overall score was calculated on a weighted and unweighted basis. The unweighted basis is simply the average of the overall evaluation criteria ratings. Figure ES-7 presents the results of the weighted scores.

Results for the evaluation of the threshold and balancing criteria are summarized below.

Table ES-8. Comparative Evaluation of Remedial Alternatives

Evaluation Criteria				Remedial Alternative															
				1	2A1	2A2a	2A2b	2A3	2A4a	2A4b	2A4c	2B	3A1	3A2	3B	3C	4A	4B	4C
Overall Protection of Human Health and the Environment	Summary of Long-Term Effectiveness and Permanence	Magnitude of Residual Risk	RAOs	Not expected to achieve RAOs.	PRGs are not achieved for RAO 1, except 2A4c and 4C; however RAO 1 is achieved for the other alternatives through a combination of active remediation and institutional controls. PRGs associated with RAOs 2, 3, and 4 are achieved for all alternatives at completion of construction.														
			Potential for Re-Exposing Remaining Subsurface Contamination	Largest amount of subsurface contamination and greatest potential for re-exposure.	Very low potential (2A4c) - Low potential (2A2b, 2A4a, 2A4b) - Low to moderate potential for re-exposure.								Low potential (3A2) - Low to moderate potential for re-exposure.				Very low (4A, 4B) - No potential (4C) for re-exposure.		
		Adequacy & Reliability of Controls	Institutional Controls: Site-wide ICs	No ICs implemented.	ICs are required for all remedial alternatives to manage residual seafood consumption risks except Alternative 4C.														
			Institutional Controls: Future use restrictions (based on area remediated by capping)		Moderate (10.3 acres) - Moderate to High (18 acres) - High (30 to 40 acres)								Very low (3C) - Low (3A, 3B)				No cap area, no future use restrictions		
			Long-term Operation and Maintenance Monitoring (based on area remediated by capping and ENR)		Moderate (18 acres) - Moderate to high (30 acres) - High (40 acres)								Moderate to high (30 acres)				Moderate (4A - 18 acres) - Moderate to high (4B - 30 acres) - No long-term O&M (4C) required		
	Summary of Short-Term Effectiveness			No short-term impacts but contamination remains above protective levels.	Low short-term impacts during construction.					Low to moderate		Moderate	Moderate short-term impacts during construction.				High short-term impacts during construction and long time to achieve RAOs.		
	Summary of Overall Protection of Human Health and the Environment			Does not provide adequate overall protection to human health and the environment.	Alternatives 2, 3, and 4 provide adequate overall protection to human health and the environment. Alternatives with longer construction periods have proportionately greater short-term impacts. Alternatives that dredge or cap a larger surface area have a lower potential for re-exposure. Re-exposure of subsurface contaminated sediment is likely to be localized and have limited effect on sitewide averages.														
Comply With or Waive ARARs	Compliance with ARARs	Water Quality Standards		Not expected to comply.	Water quality improvements are anticipated from sediment remediation and source control. Similar long-term water quality improvements are expected for all alternatives.														
		Sediment Management Standards			Alternatives 2, 3, and 4 are predicted to achieve the SQS immediately following implementation.														
		MTCA	Human Health Seafood Consumption		Alternatives 2, 3, and 4 require engineering and institutional controls to comply with MTCA because the MTCA requirement to achieve natural background is generally not achievable. Only Alternatives 2A4c and 4C would achieve PRGs at completion of construction.														
			Human Health Direct Contact		All alternatives achieve the cumulative direct contact goal of 1×10^{-5}.														
	Summary of ARARs				All alternatives comply.														
Achieve Threshold Requirements				No	Yes								Yes				Yes		
Long-Term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated Sediment Remaining in the Subsurface)			Largest amount of subsurface contamination and greatest potential for re-exposure.	Low potential to low to moderate potential for re-exposure.								Low to moderate potential for re-exposure.				Very low to no potential for re-exposure.		
	Adequacy & Reliability of Controls	Long-term Operation and Maintenance Monitoring (based on area remediated by capping and ENR)		No monitoring	Moderate (18 acres) - Moderate to high (30 acres) - High (40 acres)								Moderate to high (30 acres)				Moderate (18 acres) - Moderate to high (30 acres) - No long-term O&M required		
		Magnitude and Duration of Institutional Controls	Seafood consumption advisories, public outreach, and education	No ICs	Seafood consumption advisories, public outreach, and education are required for the Lockheed West site and are of similar magnitude and duration regardless of alternative except Alternative 4C.														
			Future use restrictions (based on area remediated by capping)		Moderate (10.3 acres) - Moderate to High (18 acres) - High (30 to 40 acres)								Very low (3C) - Low (3A, 3B)				No cap area, no future use restrictions		
	Summary			No ICs	The need for monitoring and maintenance is higher for Alts. 2, 3 and less for Alt. 4. ICs are required and of similar magnitude/duration except for complete removal alternatives. Monitoring of waterway permitting and use activities is highest for containment focus alternatives. Alt. 4C require no monitoring and notification activity because no subsurface contaminated sediment remains in place.														
Short-term Effectiveness	Protection of Workers, Community, and Environment during Construction			No short-term impacts but contamination remains above protective levels.	Low short-term impacts during construction.					Moderate short-term impacts during construction.			Moderate short-term impacts during construction.				High short-term impacts during construction and long time to achieve RAOs.		
Implementability	Technical and Administrative Feasibility	Total actively remediated area (acres)		n/a	Short construction period. Low potential (all except Alt. 2A4c) - Moderate potential (2A4c) for tech./ admin. difficulties and schedule delays.								Short (3A, 3B) - Moderate (3C) construction period. Moderate potential for tech./ admin. difficulties and schedule delays.				Moderate (4A) - Long (4B, 4C) construction period. Moderate (4A) - High (4B, 4C) potential for tech./ admin. difficulties and schedule delays.		
		Performance dredge volume																	
	Summary			High	Moderate - High								Moderate				Low		
Costs	Total (MM$)			0	17	18.7	25	20.2	22.4	34.1	43.8	33.3	28.9	47.5	37.5	47	92.3	204	302.8

ARAR = Applicable or Relevant and Appropriate Requirements; ENR = Enhanced Natural Recovery; IC = Institutional Controls; MM$ = millions of dollars; MTCA = Model Toxics Control Act; n/a = not applicable; O&M = operation, maintenance, monitoring;
PRG = preliminary remediation goal; RAO = remedial action objective

Table ES-9. Relative Scoring and Ranking Process for Remedial Alternatives

Evaluation Criteria (Ranking Weight)			Basis	Scale [1/]	
CERCLA Criteria		FS Analysis Factors		0	10
Threshold	**1. Overall Protection of Human Health and Environment (0%)**	• How alternative provides human health and environmental protection	RAO1 [2/]	baseline	achievement of PRGs
			RAO2	baseline	achievement of PRGs
			RAO3	SMS exceedances	No SMS
			RAO4	baseline	achievement of PRGs
		• Protection of workers during remedial actions • Environmental impacts	Relative to volume of contaminated material removed, handled and transported	1.5 MM cy	0 cy
	2. Compliance with ARARs (0%)	• Compliance with chemical specific, location specific, and action specific ARARs	RAO3	Baseline surface locations > SMS (54)	0 surface locations > SMS
Primary Balancing	**3. Long-term Effectiveness and Permanence (50%)**	• Magnitude of residual risks	Residual risk in the surface sediments	baseline	Achievement of RAO 1 PRGs
		• Magnitude of residual risk from reexposure of subsurface cores	Number of cores with SMS exceedances	baseline	0
			# cores < 3 ft no cap # cores < 3 ft ENR # cores < 3 ft under cap	Weighting: 1.0 Weighting: 0.7 Weighting: 0.1	
		• Mass of contaminants removed	Relative to the mass of risk-driver contaminants removed	0 MT	200 MT
		• Re-exposure risk due to seismic events	Relative to area of dredging to non dredging area and the liquefaction-induced hazard	no hazard 10	high hazard 0
		• Reliability of technology	Area actively remediated Relative factor of technology and area of implementation	0 0 eq acres [3/]	40 acres 40 eq acres
			Acres of Dredge Acres of Cap Acres of ENR	Weighting: 9 Weighting: 8 Weighting: 5	
		• Monitoring considerations	Relative to area of cap and ENR	40 acres	0 acres
		• Adequacy and reliability of controls	Institutional Controls required long term	Cap (3), none-cap (7)	none
			Future use limitiations (relative to acres capped)	40 acres	0 acres
			Port future development limitations	yes	none
			Acres of ENR and no action taken	38 acres	0 acres
	4. Reductions in Toxicity, Mobility, and Volume Through Treatment	n/a	n/a	n/a	n/a
	5. Short-term Effectiveness (25%)	• Protection of community during remedial actions	Relative to volume material removed, handled and	1.5 MM cy	0 cy
		• Protection of workers during remedial actions • Environmental impacts	Relative to volume material removed, handled and transported	1.5 MM cy	0 cy
		• Time until remedial action objectives are achieved	Time to complete	9 yrs	0 yr
	6. Implementability (25%)	• Ability to construct and operate technology • Reliability of technology • Ease of undertaking additional remedial action if necessary • Monitoring considerations • Administrative feasibility • Availability of services and materials • Implementability of ICs • Time until remedial action objectives are achieved	Relative factor of technology and area of implementation	40 eq acres [3/]	0 eq acres
			Acres of Dredging Acres of Capping Acres of ENR	Weighting: 10 Weighting: 6 Weighting: 4	
			Relative to volume material removed, handled and transported	1.5 MM cy	0 cy
			Time to complete [4/]	9 yrs	0 yr
	7. Cost	• Total direct/indirect costs including all labor, equipment, and material costs • O&M costs, monitoring	Total cost ($ MM)	n/a	n/a

Notes:

1/ A score of 0 represents a low ranking for the given metric. A score of 10 represents a high ranking for a given metric. Scores of 0 or 10 do not necessarily represent the results for the lowest or highest alternatives, but represent the high and low relative scores for the shown scale. The alternatives are scored on a linear scale between the high and low points.

2/ Average performance for all COCs is ranked. See Table ES-7 for performance toward reaching RAO1 PRGs for individual risk-driver COCs.

3/ Rankings based on the area over which the technology is applied multiplied by the technology factor divided by the acreage of the study area

4/ For Implementability, because Alternative 1 does not achieve the RAOs the ranking for time to complete is given a 0.

ARAR = Applicable or Relevant and Appropriate Requirements; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; cy = cubic yards; ENR = enhanced natural recovery; eq acres = equivalent acres; IC = institutional control; MM = million; MT = metric ton; n/a = not applicable; O&M = operation, maintenance, monitoring; PRGs = Preliminary Remedial Goals; RAO = remedial action objective; SMS = sediment management standards

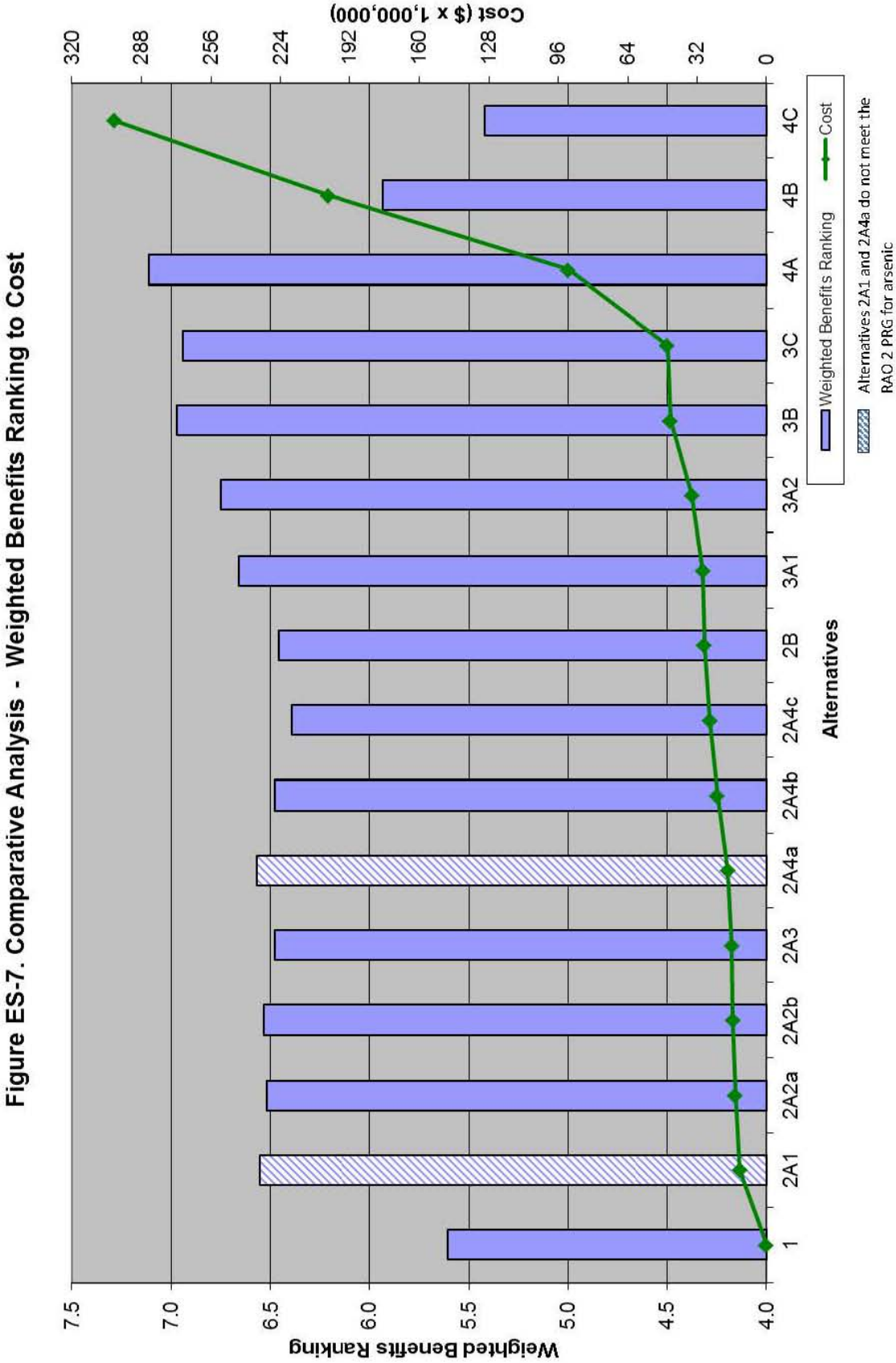


Figure ES-7. Comparative Analysis - Weighted Benefits Ranking to Cost
Weighted Benefits Ranking
Cost ($ x 1,000,000)
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
320
288
256
224
192
160
128
96
64
32
0
1
2A1
2A2a
2A2b
2A3
2A4a
2A4b
2A4c
2B
3A1
3A2
3B
3C
4A
4B
4C
Alternatives
Weighted Benefits Ranking
Cost
Alternatives 2A1 and 2A4a do not meet the RAO 2 PRG for arsenic

Overall Protection of Human Health and the Environment

Alternative 1 was analyzed in the detailed evaluation and comparative analyses as the CERCLA baseline alternative; it does not achieve any of the RAOs and it provides the least protection of human health and the environment. Other alternatives meet the threshold criterion for overall protection of human health and the environment by achieving the four RAOs through the implementation of an engineered remedy, application of appropriate institutional controls, and by providing monitoring to ensure the preliminary remediation goals associated with the RAOs are achieved. It is not technically feasible for any of the alternatives except Alternative 2A4c (conventional capping to the study area boundary) and 4C (removal to the study area boundary) to achieve the preliminary remediation goals for the human seafood consumption assuming use of natural background concentrations. Other alternatives provide incremental risk reduction and average 89 percent to 99 percent progress towards reaching RAO 1 preliminary remediation goals from the mean baseline conditions (see Table ES-7); therefore, all alternatives, except 4C, would require institutional controls (seafood consumption advisories, public education, and outreach) to reduce human exposures to resident seafood. Alternatives 2A4c (conventional capping to the study area boundary) and 4C (removal to the study area boundary) would achieve RAO 1 preliminary remediation goals at the completion of construction and therefore would not require a specific seafood consumption advisory; however, the existing regional consumption advisories would still apply. The reason for this is there will be restrictions on the number of fish that can be consumed even if the cleanup meets the preliminary remediation goals (natural background levels in most cases) that are higher than the risk-based threshold concentrations. At the end of construction and in the short term, the remediated areas will result in a clean surface. In the long term, with sediment mixing (as described for ENR) and new sediment deposition at the Site, the surface sediment concentrations are likely to increase, especially for PCBs and cPAHs where the sediment concentrations in Elliott Bay are above the natural background concentrations.

Alternatives 2 through 4 are predicted to reduce surface sediment contaminant concentrations to levels that protect humans from adverse effects associated with direct contact with sediment (RAO 2). Alternatives 2 through 4 will protect the benthic community (RAO 3) by reducing contaminant concentrations in the surface sediments to below SQS concentrations. In addition,

Alternatives 2 through 4 are predicted to protect wildlife (RAO 4) by reducing total risk driver contaminants of concern concentrations below levels that correspond to a non-cancer hazard quotient less than 1 for wildlife that consume resident seafood.

Alternatives that include dredging or capping a larger surface area (e.g., Alternatives 2A4c, 4C) have a lower potential for subsurface contamination to be re-exposed by natural or mechanical disturbances, such as scour. The containment-focus alternatives (Alternative 2) with smaller active footprints would leave slightly more subsurface contamination that could potentially be re-exposed by physical disturbance mechanisms (e.g., high-flow scour, propeller wash, and construction). The risk for re-exposing remaining subsurface contamination due to seismic events is considered moderate for Alternative 2, low to moderate for Alternative 3 and 4A, and low for Alternatives 4B and 4C. The risk and potential hazard from a seismic slope stability failure or a larger scale flow slide is same for all alternatives. If re-exposure of subsurface contaminated sediment were to occur, it is likely to be localized and have limited effect on sitewide averages. In addition, inspection and maintenance will prevent long-term exposure of the contaminated sediment. Alternatives with longer construction periods (i.e., Alternatives 4A, 4B, and 4C) have proportionately greater short-term environmental impacts.

In summary, Alternatives 2, 3, and 4 achieve the threshold criterion of overall protection of human health and the environment, achieving RAO 1 through implementation of an engineered remedy and institutional controls, and achieving PRGs associated with RAO 2, 3, and 4 through implementation of the engineered remedy. Alternative 1 does not achieve this threshold criterion.

Compliance with Applicable or Relevant and Appropriate Requirements

The remedial alternatives were developed and evaluated against their compliance to key applicable or relevant and appropriate requirements (ARARs), including state Sediment Management Standards and the state Model Toxic Control Act. Alternative 1 does not satisfy the threshold requirement of complying with ARARs. Alternatives 2, 3, and 4 substantively comply with ARARs with institutional controls.

The Model Toxic Control Act defines natural background as the cleanup standard required for final remedies when natural background concentrations are higher than the calculated risk-based

cleanup levels. The EPA has determined that this aspect of the Model Toxic Control Act is an ARAR under CERCLA and has stated that it is also an ARAR for the Lockheed West Site. The remedial alternatives (except Alternatives 2A4c and 4C) are not expected to achieve concentrations at or below natural background concentrations. The Model Toxic Control Act natural background ARAR is addressed by using institutional controls designed to reduce human exposure to resident fish and shellfish.

The Comprehensive Environmental Response, Compensation, and Liability Act requires that all ARARs be met or waived as part of the cleanup process. A waiver of the Model Toxic Control Act requirement for use of natural background for cases in which the risk-based threshold concentration is lower than natural background (i.e., for PCBs, cPAHs, lead, and arsenic) will be necessary for completion of the cleanup action.

Surface water quality at the Site is expected to improve as a result of sediment remediation. However, compliance with some of the federal or state ambient water quality standards may not be feasible, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs.

Long-Term Effectiveness and Permanence

General analysis factors considered during the comparative evaluation of alternatives for long-term effectiveness and permanence include magnitude of residual risks and adequacy and reliability of controls. Alternatives that include dredging across a greater surface area leave less contaminated subsurface sediment behind and reduce the risk of potential future exposures due to high-flow events or vessel scour. More capped surface area poses lower risk from subsurface sediments than for areas addressed by enhanced natural recovery because caps are engineered to remain structurally stable under site-specific conditions. The comparison is slightly different when seismic events are considered. The re-exposure potential of subsurface contamination due to seismic events is slightly higher for cap and ENR areas than for the dredge areas. Based on seismic analysis findings (Appendix H), the risk of potential seismic-induced disturbance of subsurface sediments and the potential hazard is higher for Alternatives 1, 2, 3A1, 3A2, and 3B than for Alternatives 3C and 4. The predicted hazards are less for a 100-year event than for the 500- and 2,500-year events.

The evaluation of the magnitude of subsurface residual risks suggests that Alternative 1 has the greatest potential for re-exposure because all subsurface contamination remains in place and no actions are taken to reduce the risks. Complete removal alternatives (Alternatives 4A, 4B, and 4C) pose “no” potential to “very low” potential for re-exposure of contaminants because the contaminated sediments are physically removed, thereby eliminating any residual risk. The potential for re-exposure under containment-focus alternatives (Alternative 2) and alternatives with larger enhanced natural recovery footprints pose slightly higher potential for re-exposure but still ranked as “low” to “low to moderate” potential because the remedial alternatives are designed to identify and actively manage areas prone to natural or mechanical disturbances. In the long term, re-exposure of buried contamination by physical disturbances including seismic events would generally be confined to small, localized areas, which could cause localized risks to benthic organisms if left unrepaired for a significant period. Such disturbances would not significantly increase residual sitewide risks (i.e., direct contact and seafood consumption risks). In addition, monitoring, institutional controls, and contingency actions will be used to prevent or respond to problem areas.

Alternatives 2 through 4 (except Alternative 4C) each require a set of controls consisting of monitoring, maintenance, and institutional controls, with contingency actions and periodic reviews (e.g., every 5 years). The alternatives differ in the scope and duration of long-term operation and maintenance monitoring, which are in proportion to the total surface area designated for capping, enhanced natural recovery, and dredge footprints.

Alternative 1 has the lowest relative score for long-term effectiveness and permanence because it leaves the largest amount of subsurface contamination in place and does not provide any long-term monitoring to ensure reliability of controls. Alternatives 4A, 4B, and 4C have the highest scores because they remove the most contaminated sediments. The other alternatives have relative scores between these values based on the mass of contaminants removed (i.e., applicable to Alternatives 2B, 3A1, 3A2, 3B, and 3C), re-exposure potential from remaining subsurface contamination, the scale of institutional controls, and the extent of monitoring and maintenance requirements.

Reductions in Toxicity, Mobility, and Volume through Treatment

Because no treatment is included with any of the alternatives, there would be no reduction of toxicity, mobility, or volume through treatment. Some reduction in toxicity, mobility, and volume would occur through removal or physical isolation of the most contaminated sediment.

Short-Term Effectiveness

Short-term effectiveness addresses impacts that result from implementation and active remediation. Generally, the alternatives that represent the least impact to the community, Site workers, and the environment during their implementation and that achieve protectiveness in the shortest time are ranked most favorably. More dredging involves the most construction, handling, and transportation activities and is considered the least protective of workers. More dredging represents the greatest risk to the environment and is the least protective of the community because dredged material will need to be transported through the community to an off-site landfill by barge, truck, and rail, increasing the potential for physical hazards and spills. Other community impacts from transportation and heavy equipment operations include air emissions, noise, and nighttime illumination of operations. Seafood consumption that occurs during construction presents a short-term risk to the community because concentrations of contaminants of concern in resident seafood are likely to be higher during construction as a result of contaminated sediment resuspension and biological uptake.

Alternative 1, No Action, scored the highest in this category because no active remedial actions would be performed. Alternative 4C, the most extensive complete removal alternative, received the lowest score followed by Alternatives 4B and 4A, respectively. Other containment-focus and removal-focus alternatives scored relatively high due to their short construction period or minimal dredge components, which would therefore result in fewer short-term impacts to the Site workers, community, and environment (Table ES-8).

Implementability

This evaluation criterion is used to consider the technical and administrative feasibility of implementing the remedial alternatives and availability of services and materials. The evaluation is focused on technical and administrative implementability because resources for the remedial

technologies are available from multiple vendors and procurable through competitive bidding in the Pacific Northwest.

Containment-focus alternatives have slightly higher (more favorable) technical and administrative implementability scores than the removal-focus and complete removal alternatives. Removal-focus and complete removal alternatives exhibit the least relative implementability performance because they involve more on-site and off-site construction activities during dredging, handling, transportation, and disposal of the sediments. Consistent with this discussion, Alternative 2A1 scored highest in this category followed by Alternatives 2A4a and 2A2a while other containment- and removal-focus alternatives scored slightly lower and complete removal Alternatives 4A, 4B, and 4C had lower scores, with the lowest being Alternative 4C.

Cost

Other than the No Action alternative at $0, costs for the alternatives range from $17.0 million (Alternative 2A1) to $302.8 million (Alternative 4C). The total cost represents the sum of the direct capital costs (materials, equipment, and labor), indirect capital costs (engineering, management, and contingency allowances), and annual and periodic costs (operation and maintenance costs, monitoring, and ongoing administration). The costs are 30-year net present value. Institutional controls related to future use restrictions have been incorporated into the evaluation of the adequacy and reliability of controls under long-term effectiveness and permanence and implementability. These future use restrictions will be minimized during the design of the remedy because the Site is a tribal U&A area and the remedy should be designed to reduce conflicts with or restrictions on tribal treaty fishing rights or other treaty protected rights. Potential third-party costs (e.g., easements) were not included in this evaluation. These total costs, which are developed to allow the comparison of the remedial alternatives, are estimated with expected accuracies of -30 to +50 percent, in accordance with the EPA document *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*.[3] Remedial costs are summarized in Tables ES-7 and ES-8 and illustrated in Figure ES-7.

[3] U.S. Environmental Protection Agency. 1988. *Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA.* Publication 9355.3-01. EPA/540/G-89/004. October. Washington, DC.

ES.11 IDENTIFICATION OF BEST-SUPPORTED REMEDIAL ALTERNATIVE

Identification of the best-supported alternative is based on both the individual evaluations of the remedial alternatives against the CERCLA evaluation criteria and the comparative evaluation of the remedial alternatives. The total weighted rating scores for the active remedial alternatives range from 5.4 to 7.1. This narrow range is attributable primarily to two key factors: 1) the predicted outcomes related to the remedial action objectives are similar for all alternatives, and 2) differences between the alternatives for individual criteria are diminished when those criteria are averaged to calculate total benefits. More dredging does not necessarily result in higher overall scores because of higher short-term impacts to the workers, community, and environment and lower technical and administrative feasibility. More reliance on isolation through capping can result in higher scores due to its benefits in reducing short-term impacts and having easier and simpler technical and administrative implementability. The weighted rating scores for the alternatives demonstrate that the higher cost alternatives show little or no increase in overall benefit with additional costs.

Figure ES-8 includes a summary of remedial technologies (i.e., dredging, capping, enhanced natural recovery), the size of the active remedial footprint (acres), the removal volumes (cubic yards), the weighted benefit scores, and cost of the alternatives. This figure demonstrates that regardless of the remedial technology, the remedial footprint, or dredge volume, there is proportionally little difference in the overall benefits of the alternatives. Any differences in overall protectiveness of Alternatives 2, 3, and 4 are largely in the context of short-term and long-term effectiveness (see Table ES-8). Figure ES-9 presents the weighted benefits per unit cost for each alternative and demonstrates a general trend for declining cost/benefit ratio as the alternative costs increase.

Based on the detailed comparative evaluation of the remedial alternatives, Alternative 2A2a is identified as the best-supported alternative for implementation at the Lockheed West Site because of its following characteristics:

- Alternative 2A2a achieves site-specific PRGs associated with RAOs and ARARs are achieved through implementation of the engineered remedy and application of institutional controls. The remedy produces a clean surface over the areas remediated at

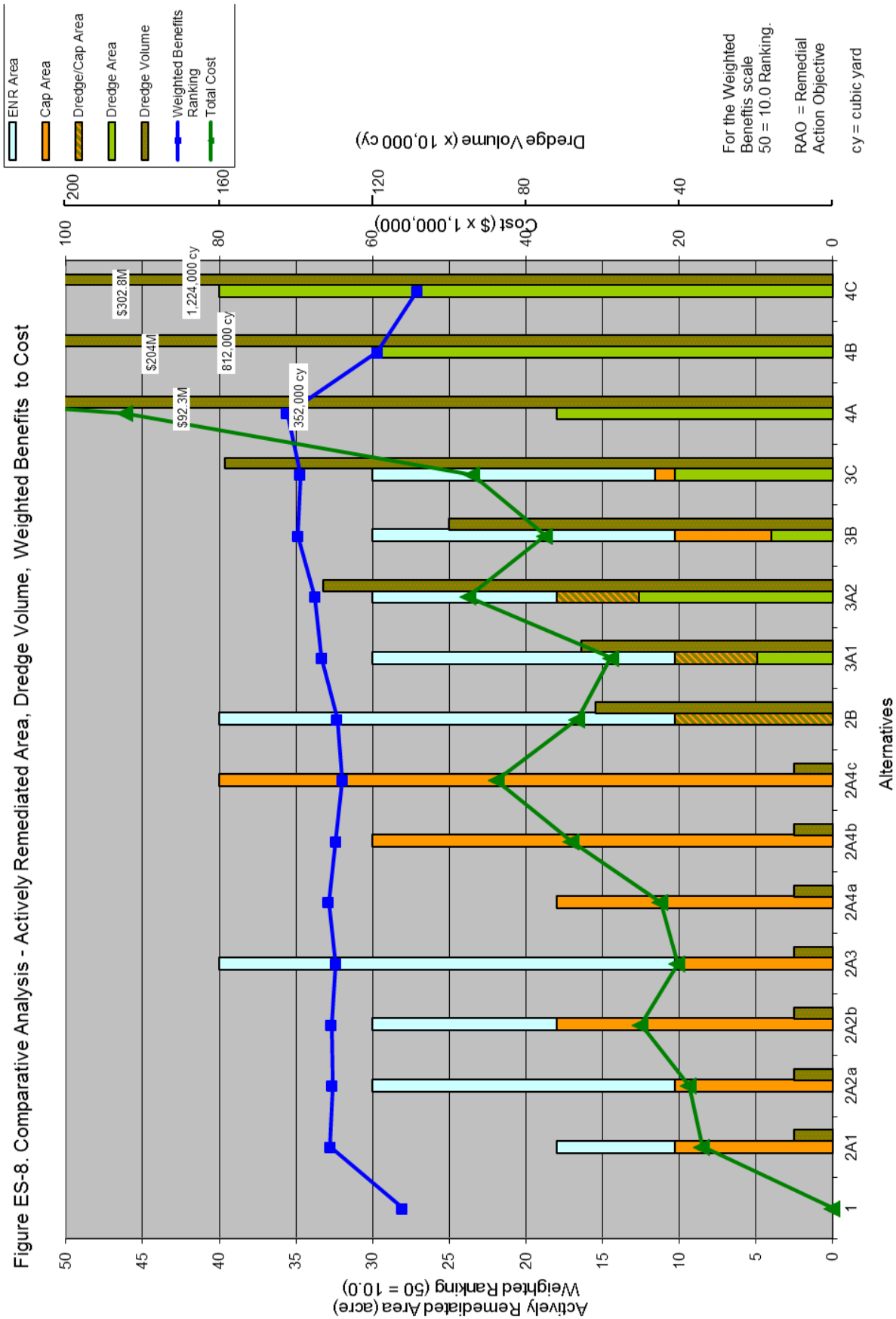
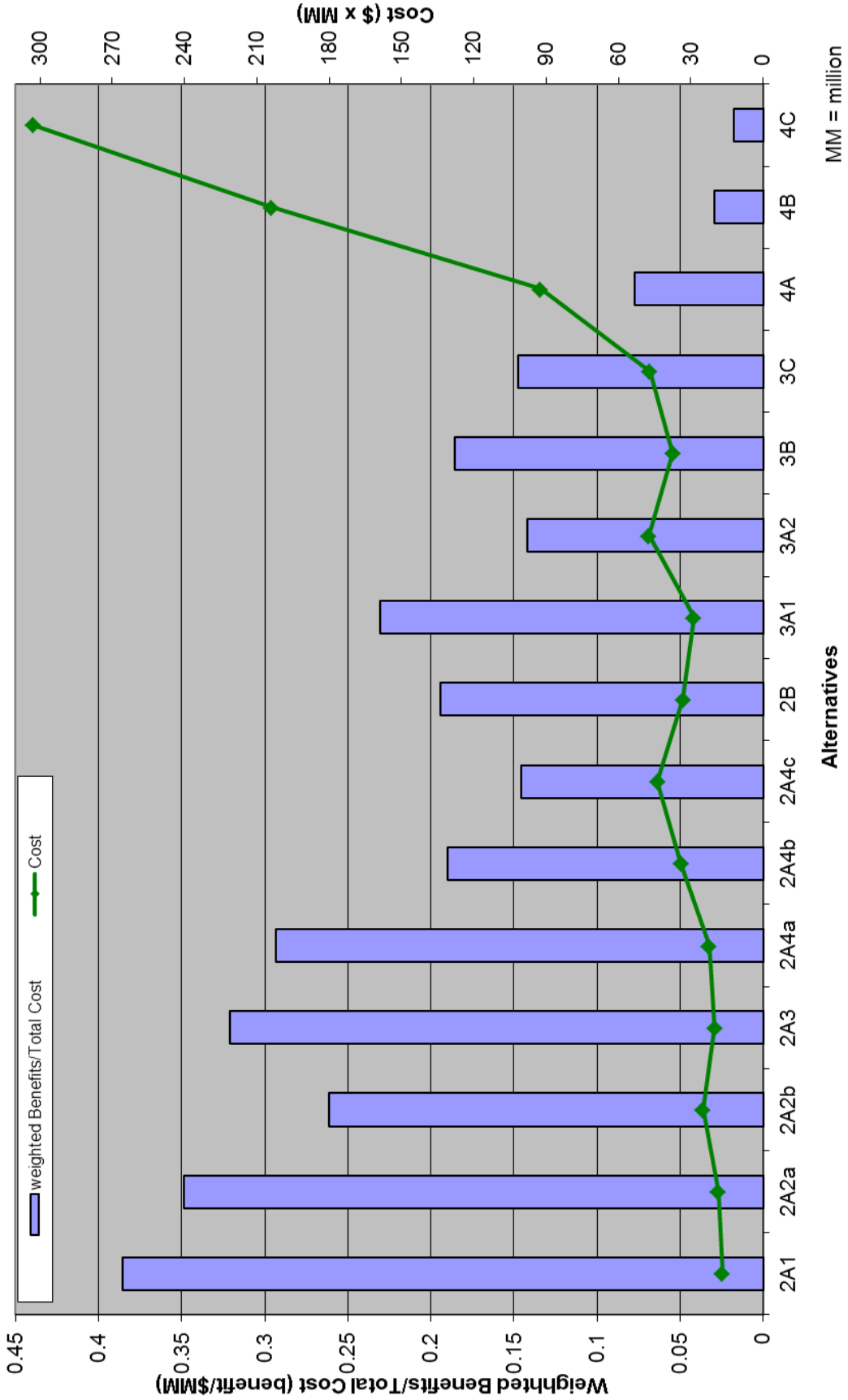


Figure ES-8. Comparative Analysis - Actively Remediated Area, Dredge Volume, Weighted Benefits to Cost

Figure ES-9. Remedial Alternatives Comparative Analysis - Weighted Benefits Ranking per Unit Cost



the end of construction achieving the PRGs for all RAOs in the short-term. Over the long term, the surface and near surface sediments will reach an equilibrium concentration through mixing as described in the ENR application for the Site. Some deposition of new sediment over the post-construction surface is expected to occur. The long-term concentrations for COCs at the Site are expected to fall between the natural background levels and the concentrations found in the Elliott Bay region.

- All active alternatives, except Alternative 4C, have similar seafood consumption advisories and a public education/outreach program. To meet RAO 1, institutional controls are needed for Alternative 2A2a, under which 93 percent progress toward meeting PRGs for protection of human health through seafood consumption (i.e., RAO1 PRGs) is achieved through capping and ENR remedial activities. However, as discussed above, regardless of the selected alternative the existing regional consumption advisories would still apply. The reason for this is there will be restrictions on the number of fish that can be consumed since the PRGs (natural background in most cases) are higher than the risk-based threshold concentrations.
- Alternative 2A2a achieves the PRGs associated with RAO 2, 3, and 4 through implementation of the engineered remedy at the end of construction and in the long term.
- Alternative 2A2a scores high under the Comprehensive Environmental Response, Compensation, and Liability Act balancing evaluation criteria.
- The remedy includes former shipway area remediation, shoreline remediation, shoreline stabilization, and intertidal habitat restoration and improvements in addition to the subtidal remediation. Shoreline remediation incorporates removal/cap/backfill to allow tribal fishing and clamming.
- There is low to moderate potential for re-exposure of remaining subsurface contamination. There is moderate hazard predicted due to seismic events. It is feasible to repair the cap if such damage occurs. Localized impacts are unlikely to affect sitewide average concentrations.
- The capped area footprint and associated restrictions on potential future uses are limited to the former dry dock areas. The cap would encumber but does not preclude reasonably anticipated future land use issues provided by the Port of Seattle and DNR.
- Potential future use restrictions related to cap areas can be minimized during design by increasing the thickness of the cap to allow anchoring and grounding of small vessels and by coordinating with the Muckleshoot and Suquamish Tribes, Port of Seattle, and DNR.

- There are low risks to the Site workers, community, and environment during implementation.
- Technical and administrative implementability during construction is considered high.
- Adequacy and reliability controls are well-established to ensure the integrity and the performance of the remedy through a combination of monitoring, maintenance, and institutional controls that would be designed and implemented over the next 30 years.
- The alternative has the additional benefit of having the smallest environmental footprint of remedial action after Alternative 2A1 in terms of greenhouse gas emissions, fuel consumption, use of natural resources, and landfill volume requirements.
- Alternative 2A2a achieves equal overall benefits relative to other alternatives at a lower cost, providing the most cost-effective and protective remedy.

Under Alternative 2A2a, conventional sediment capping and enhanced natural recovery would be used to contain contaminated sediments within the remedial action area, creating a clean surface suitable for re-establishment of aquatic biota. In areas that are capped, the cap would be of sufficient thickness and gradation to ensure isolation of impacted sediments and to withstand natural and vessel-related erosion forces. Alternative 2A2a includes the following:

- Conventional capping over the areas defined by the risk-driver contaminants of concern to the surface Cleanup Screening Level footprint (10.3 acres) and enhanced natural recovery over the remaining area to the Elliot Bay Urban footprint (19.7 acres);
- Former shipway area remediation, shoreline remediation, shoreline stabilization, and intertidal habitat restoration and improvements (about 2 acres and removal of approximately 10,000 cubic yards), which allow for the harvesting of shellfish from intertidal areas;
- Long-term operation and maintenance monitoring program to verify performance of the cap and to respond to potential cap damage; and
- Institutional controls—public outreach, education, and seafood consumption advisories (as part of regional Elliott Bay advisories); proprietary controls (e.g., easement of cap area); monitoring and notification of waterway users, which would be minimized or eliminated during design; and a site registry to apply to the conventional capping area.

Estimated costs for this alternative are $18.7 million dollars. Figure ES-10 illustrates active remedial actions of the best-supported alternative.

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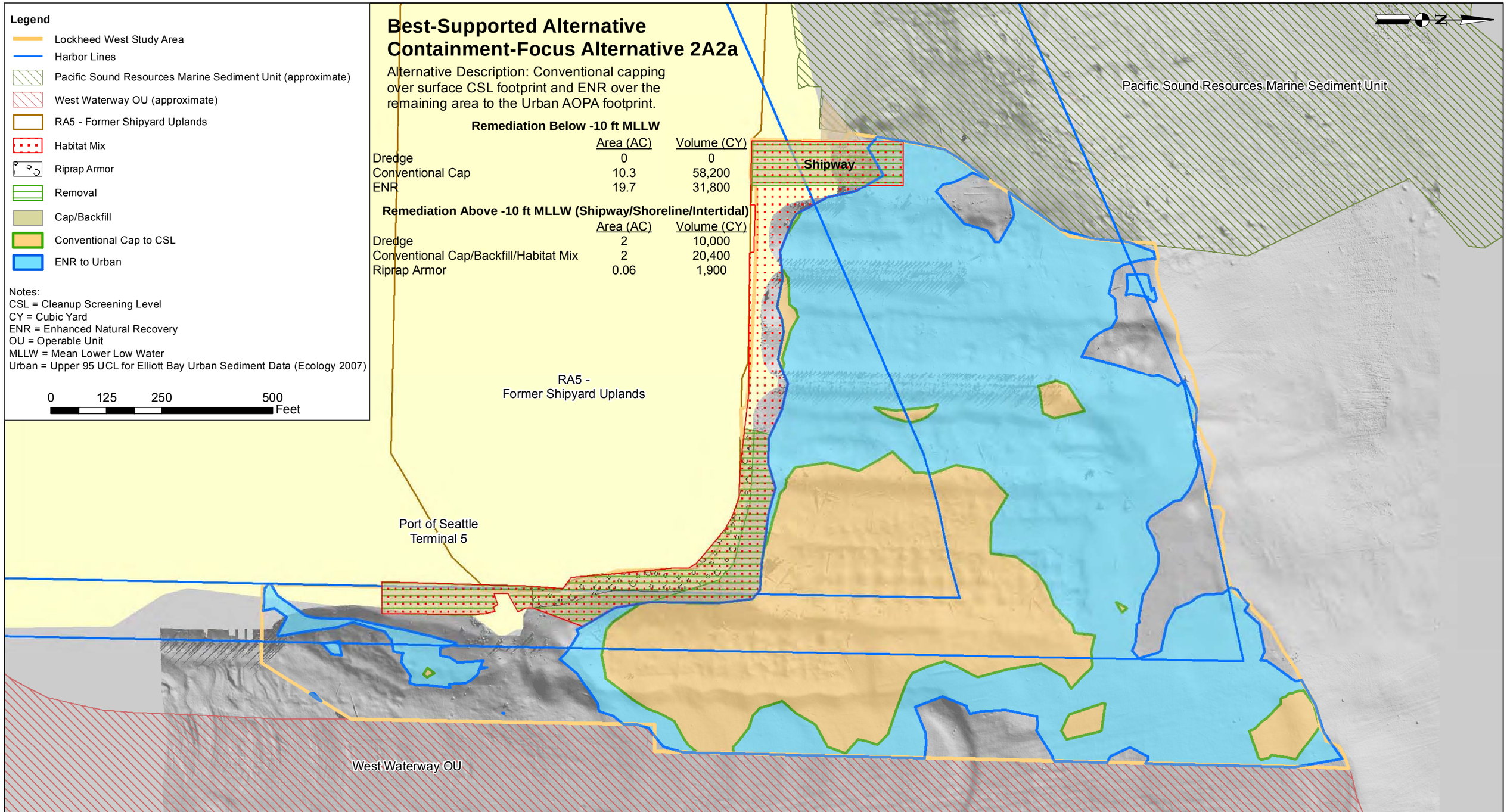

TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure ES-10
Best-Supported Alternative
Alternative 2A2a

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ACRONYMS AND ABBREVIATIONS

§	section
3-D	three-dimensional
95 UCL	95 percent upper confidence limit
AOPA	area of potential action
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
BSAF	biota-sediment accumulation factor
CAD	confined aquatic disposal
CAP	Cleanup Action Plan
CDF	confined disposal facility
CEM	Coastal Engineering Manual
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHE	Coast and Harbor Engineering, Inc.
cm/sec	centimeter per second
CO_2	carbon dioxide
COC	contaminant of concern
COI	contaminant of interest
COPC	contaminant of potential concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSF	cancer slope factor
CSL	cleanup screening level
CSO	combined sewer overflow
CST	column settling test
DDD	dichlorodiphenyldichloroethane
DDT	dichlorodiphenyltrichloroethane
DMMP	Dredged Material Management Program
DNR	Washington State Department of Natural Resources

DRET	dredge elutriate test
DVD	digital versatile disk
Ecology	Washington State Department of Ecology
EIS	environmental impact statement
ENR	enhanced natural recovery
EPA	U. S. Environmental Protection Agency
EPC	exposure point concentrations
ERA	Ecological Risk Assessment
ESA	Endangered Species Act
ESTCP	Environmental Security Technology Certification Program
f_{oc}	fractional organic matter content
FS	Feasibility Study
ft/sec	feet per second
g/cc	grams per cubic centimeter
GRA	General Response Action
HHRA	Human Health Risk Assessment
HI	hazard index
HPAH	heavy-weight polycyclic aromatic hydrocarbon
HQ	hazard quotient
K_d	solid/water distribution coefficient
K_{oc}	organic carbon partitioning coefficient
K_{sp}	solubility product
LAET	lowest apparent effects threshold
2LAET	second lowest apparent effects threshold
LDC	Laboratory Data Consultants, Inc.
LDW	Lower Duwamish Waterway Superfund site
Lockheed Martin	Lockheed Martin Corporation
Lockheed West Site	Lockheed West Seattle Superfund Site
LOAEL	lowest observed adverse effects level
LPAH	light-weight polycyclic aromatic hydrocarbons

LSSOU	Lockheed Shipyard No. 1 Sediment Operable Unit
µg/kg-dw	microgram per kilogram dry weight
µg/L	microgram per liter
µm	micrometer
mg/kg-dw	milligram per kilogram dry weight
mg/kg-OC	milligram per kilogram organic carbon
mg/kg-ww	milligram per kilogram wet weight
MCUL	minimum cleanup level
MLLW	mean lower low water
MNR	monitored natural recovery
mt/yr	metric tons per year
MTCA	Model Toxics Control Act
NAD	North American Datum
NCP	National Contingency Plan
ng/kg-dw	nanogram per kilogram dry weight
nm	nanometer
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no observed adverse effects level
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	National Research Council
O&M	operation and maintenance
OMMP	operations, maintenance, and monitoring plan
OU	Operable Unit
Pa	Pascal
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
PM_{10}	particulate matter less than 10 microns in diameter
Port	Port of Seattle

ppb	parts per billion
PQL	practical quantitation limit
PRG	preliminary remediation goal
PSR	Pacific Sound Resources
QAPP	Quality Assurance Project Plan
QC	quality control
RA	remediation area
RAL	remedial action level
RAO	remedial action objective
RBC	risk-based concentration
RBTC	risk-based threshold concentration
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RI/FS	Remedial Investigation/Feasibility Study
RL	reporting limits
RM	river mile
RME	reasonable maximum exposure
ROC	receptors of concern
ROD	Record of Decision
SERDP	Strategic Environmental Research and Development Program
Site	Lockheed West Seattle Superfund Site
SMS	sediment management standards
SQS	sediment quality standards
SVOC	semivolatile organic compounds
SWHP	Southwest Harbor Cleanup and Redevelopment Project
TBC	to be considered
TBT	tributyltin
TCLP	Toxicity Characteristic Leaching Procedure
TEQ	toxicity equivalent quotient
TOC	total organic carbon

TPH	total petroleum hydrocarbon
TRV	toxicity reference value
TSSOU	Todd Shipyard Sediments Operable Unit
U&A	usual and accustomed
UECA	Uniform Environmental Covenants Act
USACE	U.S. Army Corps of Engineers
U.S.C.	United States Code
VOC	volatile organic compound
WAC	Washington Administrative Code
WWCN	West Waterway Confirmational Number

SECTION 1
Introduction

This Remedial Investigation/Feasibility Study (RI/FS) report summarizes the results of the activities and evaluations that have been completed by the Lockheed Martin Corporation (Lockheed Martin) for the sediment areas at the former Lockheed Shipyard No. 2, located in Seattle, Washington. This RI/FS report has been developed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Administrative Settlement Agreement and Order on Consent (U.S. Environmental Protection Agency [EPA] Docket No. CERCLA 10-2006-0321) and associated Statement of Work for the Lockheed West Seattle Superfund Site (henceforth referred to as the Lockheed West Site or Site) (Figure 1-1).

A draft RI/FS report was submitted to EPA in April 2011. The EPA provided comments to Lockheed Martin, including a request for a seismic evaluation for the Site and consideration of additional remedial alternative variations. This final RI/FS document incorporates responses to EPA comments, the results of the seismic study, and evaluation of EPA-requested alternative variations.

1.1 BACKGROUND

Authority for the cleanup of the Lockheed West Site was transferred from the Washington Department of Ecology (Ecology) to EPA Region 10 in September 2006. Pursuant to Section 105 of CERCLA, 42 United States Code (U.S.C.) § 9605, EPA proposed the Site for inclusion on the National Priorities List (NPL) on September 26, 2006. The Site was listed on the NPL on March 7, 2007.

Prior to its transfer, the Lockheed West Site (then referred to as Lockheed Shipyard No. 2) was listed as a sediment cleanup priority by Ecology, which had developed a Cleanup Action Plan (CAP) for the Site in 1996 after completion of a cleanup investigation (Ecology 1996). The Ecology CAP was never implemented, in part due to delays associated with the Southwest Harbor Cleanup and Redevelopment Project (SWHP). However, the studies supporting the

Ecology CAP produced a significant amount of data that were useful in developing and understanding the nature and extent of sediment contamination at the Site prior to implementation of the remedial investigation.

In addition to the Ecology CAP and supporting studies, other information relevant to completion of the Lockheed West Site RI/FS is available from EPA Superfund sites nearby and adjacent to the Lockheed West Site (refer to Figure 1-1). To the immediate west of the Site is the Pacific Sound Resources (PSR) Superfund site. Sediment area remedial actions were implemented at the PSR Marine Sediment Unit site in 2002. East of the Lockheed West Site is the West Waterway Operable Unit (OU) of the Harbor Island Superfund site. The West Waterway OU is subject to a No-Action Record of Decision (ROD) (EPA, 2003a). Located along Harbor Island within the West Waterway east of the Site is the Todd Shipyard Sediment OU (TSSOU). The remedial action at the TSSOU was completed in February 2007. The Lockheed Shipyard No. 1 Sediment OU (LSSOU) is located along the West Waterway south of the Todd Shipyard site. The remedial action at the LSSOU was completed in 2005. Upstream of the West Waterway OU is the Lower Duwamish Waterway Superfund site (LDW), which is currently undergoing an RI/FS to address sediment contamination.

Under the Administrative Settlement Agreement and Order on Consent, Lockheed Martin agreed to conduct an RI/FS that would support achieving a final remedy at the Site. As part of that agreement, EPA and Lockheed Martin agreed to utilize existing data and precedents set by nearby EPA-led cleanup sites, in particular, the LDW. At that time, data from the LDW indicated that the sediment cleanup criteria for aquatic organisms established by the Ecology sediment management standards (SMS; Washington Administrative Code [WAC] 173-204) would not meet EPA human health cancer-risk thresholds for polychlorinated biphenyls (PCBs) and other contaminants of concern (COCs; e.g., arsenic) based on site-specific exposures and for tribal seafood consumption. Similarly, it was recognized that risk-based sediment cleanup levels for PCBs at the LDW would be below background concentrations. Lockheed Martin and EPA recognized that similar risk assessment outcomes were likely for the Lockheed West Site based on historical shipyard COCs and EPA-required use of recent tribal seafood consumption rates and scenarios.

Based on the use of tribal seafood consumption scenarios as described in the RI/FS Work Plan for the Lockheed West Site (Tetra Tech, 2008a), Lockheed Martin and EPA recognized that "no action" and "natural recovery" as primary remedial alternatives were not likely to meet CERCLA criteria for final remedy selection, and as such are focusing on active remediation of the Lockheed West Site. However, for completeness and consistency with the CERCLA process, both "no action" and "natural recovery" are discussed and evaluated as part of this RI/FS.

1.2 PURPOSE AND OBJECTIVES

To meet the requirements of the Administrative Settlement Agreement and Order on Consent, the purpose of the RI/FS is to accomplish the following:

- Determine the nature and extent of contamination and threats to the public health, welfare, or the environment caused by the release or threatened release of hazardous substances, pollutants, or contaminants at or from the Site, by conducting an RI; and
- Identify and evaluate remedial alternatives to prevent, mitigate, or otherwise respond to or remedy releases or threatened releases of hazardous substances, pollutants, or contaminants at or from the Site, by conducting an FS.

The Lockheed West Site RI/FS has been conducted in accordance with the provisions of the Administrative Settlement Agreement and Order on Consent, the associated Statement of Work, CERCLA, National Contingency Plan (NCP), and EPA guidance. Included in the guidance under which this work was performed are the *Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988 or subsequently issued guidance), *Guidance for Data Usability in Risk Assessment* (EPA, 1992 or subsequently issued guidance) and guidance referenced therein, and guidance referenced in the associated Statement of Work, as has been amended or modified by the EPA.

1.3 PRE-RI/FS DELIVERABLES

The RI and the FS have been combined into a single document per the Administrative Settlement Agreement and Order on Consent. Also, pursuant to the same agreement, specific deliverables were completed in advance of the draft RI/FS. In addition to the specified deliverables, other interim deliverables were prepared and submitted to EPA to help reach consensus regarding important RI/FS findings, conclusions, and recommendations.

The pre-RI/FS deliverables that have been reviewed and approved by EPA include the following:

- **RI/FS Work Plan (Tetra Tech, 2008a).** This document includes the Site Characterization Sampling and Analysis Plan (Appendix C of the *RI/FS Work Plan*) and the Quality Assurance Project Plan (QAPP; Appendix D of the *RI/FS Work Plan*). EPA approved these documents in January 2007 during development of the *RI/FS Work Plan,* to allow Lockheed Martin to expedite investigation of the Site, including sediment sampling, Site surveying, and reconnaissance activities.
- **RI Data Report (Tetra Tech, 2008b).** This document includes a description of field activities and methods for physical characterization, sediment sampling and laboratory analysis. The data report and addenda include sediment, sediment porewater, and tissue analytical results as well as supporting documentation including the shoreline survey, sediment core logs, field notes, and data validation reports. It also includes analytical data report addenda for intertidal sediment samples, porewater samples, and clam tissue samples. Tables summarizing the data collected are included as Appendix A of this RI/FS report.
- **Final Ecological Risk Assessment Report (Tetra Tech and Pascoe, 2009a).** This report summarizes the receptors of concern, assessment endpoints, conceptual site model for ecological exposures, data selection and screening process, contaminants of potential concern (COPCs), ecologic exposure and effects assessment results, and risk characterization results. The Ecological Risk Assessment Report (*ERA*) is included as Appendix B to this RI/FS report.
- **Final Human Health Risk Assessment Report (Tetra Tech and Pascoe, 2009b).** This report presents the risk assessment data evaluation and screening procedures; exposure assessment including the conceptual site model and exposure scenarios, chemical screening and COPCs selection process, calculation of exposures and daily intake rates; toxicity assessment; and risk characterization results and uncertainty assessment. The Human-Health Risk Assessment Report (*HHRA*) is included as Appendix C to this RI/FS report.
- **Final Existing Information and Data Gap Report, Evaluation of Potential Sources of Remedy Recontamination (Tetra Tech, 2009a).** This report includes background information regarding the Lockheed West Site, a description of the source control conceptual model, and existing information regarding potential sources in the nearby area including overwater uses and spills, wastewater discharges, combined sewer overflows, stormwater discharges, upland contaminated sites, contaminated sediment sites, sediment

transport, and atmospheric deposition. The report also identifies remaining data needs for the source control evaluation.

- **Final Source Control Evaluation Report (Tetra Tech, 2009b).** This report addresses the data needs identified in Tetra Tech (2009a) and provides an evaluation of the potential for recontamination of the remedy from various nearby sources including stormwater, groundwater, and nearby sediment sites. The findings of this report represent a basis for refinement of the site conceptual model and for development of the remedial action objectives (RAOs) and the FS alternatives.
- **Remedial Action Objectives Technical Memorandum (Tetra Tech, 2010a).** This memorandum defines the RAOs and the range of preliminary remediation goals to be used for preparation of the FS.
- **Nature and Extent Summary Technical Memorandum (Tetra Tech, 2010b).** This memorandum describes the extent of sediment contamination for risk-driver chemicals and defines the remedial action study area for the FS.
- **Screening of Remedial Technologies and Assembly of Preliminary Alternatives Technical Memorandum (Tetra Tech, 2010c).** This memorandum presents the initial screening of technologies and preliminary assembly of alternatives for the FS.

To improve readability, the documents discussed in this section will henceforth be referenced using the following abbreviations and excluding citation:

Full Title (Citation)	Abbreviation
Remedial Investigation/Feasibility Study Work Plan (Tetra Tech, 2008a)	*RI/FS Work Plan*
Remedial Investigation Data Report (Tetra Tech, 2008b)	*RI Data Report*
Final Ecological Risk Assessment Report (Tetra Tech and Pascoe, 2009a)	*ERA*
Final Human Health Risk Assessment Report (Tetra Tech and Pascoe, 2009b)	*HHRA*
Final Existing Information and Data Gap Report, Evaluation of Potential Sources of Remedy Recontamination (Tetra Tech, 2009a)	*Source Control Information and Data Gap Report*
Final Source Control Evaluation Report (Tetra Tech, 2009b)	*Source Control Evaluation Report*
Remedial Action Objectives Technical Memorandum (Tetra Tech, 2010a)	*RAO Memorandum*
Nature and Extent Summary Technical Memorandum (Tetra Tech, 2010b)	*Nature and Extent Summary Memorandum*
Screening of Remedial Technologies and Assembly of Preliminary Alternatives Technical Memorandum (Tetra Tech, 2010c)	*RAA Memorandum*

From the beginning, the approach employed by Lockheed Martin for the successful completion of the RI/FS has been to work collaboratively with EPA and project stakeholders, including natural resource trustees. This effort has included monthly EPA meetings, as well as preparation for and presentation at various workshops and webcasts designed to facilitate communication

and understanding of key issues and project milestones. The pre-RI/FS deliverables summarized above represent important building-blocks for the RI/FS. Major findings from all of these interim deliverables are presented in this RI/FS report. This RI/FS also references these reports as appropriate, to enable in-depth review of details and supporting documentation that are not completely repeated in this RI/FS report. The final *ERA* and *HHRA* have been provided in Appendices B and C, respectively, in their entirety.

The initial phase of fieldwork included the bathymetric, topographic, and shoreline surveys that were performed prior to completion of the *RI/FS Work Plan* during 2006 and 2007. This work was performed to help develop a preliminary site conceptual model and scope out the work elements for the RI/FS. The results of the surveys are included in the *RI/FS Work Plan* and the *RI Data Report*.

1.4 RI/FS REPORT ORGANIZATION

This document incorporates both the RI and FS for the Lockheed West Site. The RI includes an extensive sampling program and human health and ecological risk assessments in order to define the nature and extent of contamination. The results of the RI culminate in the identification of risks and definition of the study area boundary to be used in the FS. The FS is used to develop and evaluate various remedial alternatives. Therefore, the RI uses the historical lease area boundaries and the FS uses the study area boundary defined in the RI.

Sections 1 through 3 of this report provide introduction and background information supporting the RI/FS work effort. Sections 4 though 8 summarize the RI component, including assessment of the nature and extent of contamination, source control, contaminant fate and transport, and baseline risk assessments. Sections 9 through 13 comprise the FS, which includes identification of remedial action objectives and preliminary remediation goals, screening of remedial technologies and process options, and development, detailed evaluation, and comparative analysis of remedial alternatives. Further details regarding the organization of this document are provided below:

- **Section 1.0 Introduction.** This section provides general project background and the purpose and scope of the RI/FS report.

- **Section 2.0 Site Background and Environmental Setting.** This section presents Site background and environmental setting information regarding the Lockheed West Site and surrounding area. This section also includes a conceptual model overview for the Lockheed West Site.
- **Section 3.0 Summary of Previous Investigations and Remediation Activities.** This section summarizes the findings of pre-RI site investigations and any remedial activities that have taken place at the Site.
- **Section 4.0 Nature and Extent of Contamination.** This section summarizes the nature and extent of the contamination at the Site. It includes a description of the data collected along with field and laboratory methods used, and project data quality objectives and the procedures used to review/validate the data and determine the usability of the data for use in the RI. Discussions on the results of the site surveys completed, sediment physical characteristics and a summary for the specific contaminants, or groups of contaminants, are included as part of this section. Tables summarizing the data collected are included in Appendix A of this report.
- **Section 5.0 Potential Contamination Sources, Pathways, and Source Control.** This section summarizes the potential sources of contamination and pathways to the Site sediments and the identified source control measures undertaken to date.
- **Section 6.0 Fate and Transport of Sediment and Sediment-Associated Chemicals.** This section summarizes the sediment transport processes in the area and the impact on the transport of contaminated sediments. The general fate and transport mechanisms in sediment and porewater for specific contaminants or groups of contaminants are discussed. The results of transport-related data and estimation techniques are summarized here as well.
- **Section 7.0 Summary of the Baseline Human Health and Ecological Risk Assessments.** This section summarizes the baseline ecological risk assessment and baseline human health risk assessment, attached as Appendices B and C, respectively.
- **Section 8.0 Key Findings of the Remedial Investigation.** This section summarizes the key findings from the RI to be carried forward into the FS.
- **Section 9.0 Remedial Action Objectives and Preliminary Remediation Goals.** This section summarizes the RAOs and the preliminary remediation goals.
- **Section 10.0 Screening of Remedial Technologies and Process Options.** This section summarizes the identification and screening of the remedial technologies and process options applicable to the Lockheed West Site.

- **Section 11.0 Development of Remedial Alternatives.** This section identifies potential remedial action areas and remedial action levels and summarizes the assembly of representative remedial alternatives. Each of the remedial alternatives developed to address the sediment RAOs is described.
- **Section 12.0 Detailed Evaluation of Remedial Alternatives.** This section presents a detailed analysis of each remedial alternative. The evaluation has been performed in accordance with the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988) with respect to the CERCLA evaluation criteria.
- **Section 13.0 Comparative Analysis of Remedial Alternatives.** This section includes a comparative analysis of the remedial alternatives. The analysis evaluates the relative performance of each alternative with respect to the nine CERCLA evaluation criteria. Based on the detailed comparative evaluation of the remedial alternatives, one best-supported alternative is identified to EPA for consideration for implementation at the Lockheed West Site.
- **Section 14.0 References**. This section provides a complete list of the cited references within this document.

Tables and figures are included at the end of each section in the order referenced within the document. A glossary of technical terms is provided after the references section and before the appendices. The document is supported by the following appendices:

- Appendix A – Data Tables
- Appendix B – Baseline Ecological Risk Assessment
- Appendix C – Baseline Human Health Risk Assessment
- Appendix D – 3-D Model Setup and Sensitivity Analysis
- Appendix E – Volume Estimates for Remedial Alternatives and Existing Site Profiles
- Appendix F – Detailed Cost Estimates for Remedial Alternatives
- Appendix G – Estimation of Short-term Effectiveness Metrics and Sustainability Measures
- Appendix H – Liquefaction Potential and Seismic Stability Evaluation of Remedial Alternatives
- Appendix I – EPA-Requested Feasibility Study Alternative Variations Technical Memorandum
- Appendix J – Response to EPA Comments

Legend

- Approximate Site Boundary: Site boundaries will be finalized in the Record of Decision.
- Highway
- Major Road
- Local Road
- RA5 - Former Shipyard Uplands
- Creek
- Railroad
- Greenbelt
- LSSOU — Lockheed Shipyard Sediment Operable Unit
- TSSOU — Todd Shipyard Sediment Operable Unit
- OU — Operable Unit

Figure 1-1 Lockheed West Site Location and Vicinity Map

0 500 1,000
Feet

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SECTION 2
Site Background and Environmental Setting

This section presents background and environmental setting information regarding the Lockheed West Site and surrounding area. This section also presents the preliminary conceptual model for the Lockheed West Site.

2.1 LOCKHEED WEST SITE BACKGROUND

A detailed discussion of Lockheed West Site background information is provided in the *RI/FS Work Plan*. A summary for the Lockheed West Site, including ownership status and Site definition, Site history, historical shipyard activities, and a brief summary of the SWHP and Terminal 5 development, is presented below.

2.1.1 Ownership Status and Site Definition

The area of investigation for the RI/FS consists of the areal extent of sediment contamination from the former shipyard operations. The Lockheed West Site is bordered by Elliott Bay on the north, the Harbor Island West Waterway OU on the east, the PSR Superfund site on the west, and Port of Seattle (Port) Terminal 5 to the south (refer to Figure 1-1). It includes approximately 7 acres of aquatic land acquired by the Port from Lockheed Martin between 1989 and 1992 and approximately 20 acres of aquatic state-owned land managed by the Washington State Department of Natural Resources (DNR) and historically leased to Lockheed Martin.

Figure 2-1 is a map of the former property boundary for the Lockheed West Site, including associated former lease areas. The upland areas associated with the former shipyard are not included in the definition for the Lockheed West Site because these areas are currently owned by the Port and addressed under Ecology oversight as part of the SWHP and Terminal 5 expansion. The historical property boundaries shown in Figure 2-1 are for purposes of illustration but do not represent the cleanup boundary. The area of investigation includes both the property occupied by

the former shipyard and the areas of Elliott Bay and the West Waterway immediately adjacent to the former shipyard property (refer to Section 4.0). The southern edge of the Lockheed West Site, as defined for the investigation in the *RI/FS Work Plan*, is represented by the mean higher high water mark (i.e., elevation +11.35 feet mean lower low water [MLLW]) along the shoreline adjacent to Terminal 5 (Figure 2-1). The eastern and northern boundaries of the historical shipyard use area were defined by the outer limits of the DNR aquatic lease areas (Outer Harbor Line).

All former leases with Lockheed Martin were assumed by the Port between 1989 and 1992. The aquatic lands south of the former DNR lease areas were sold by Lockheed Martin to the Port in 1992 (refer to Figure 2-1). The Port also acquired the upland portion of the former shipyard from Lockheed Martin for expansion of the cargo facilities at Terminal 5. Under their Port Management Agreement (22-080031), the Port assumed management authority for the following harbor area leases: 22-090031, 22-090032, 22-090033, and the filled harbor area (or "Upland") portion of harbor area lease 22-002564. In a December 5, 1996, letter to DNR, the Port deleted the non-filled portion of the harbor area leases 22-002564, 22002119, and 22-001982 from their management. Therefore, those portions of the former aquatic lease areas revert back to management by DNR.

2.1.2 Site History

Prior to development in the early 1900s, the Lockheed West Site and vicinity consisted of an intertidal deltaic environment at the mouth of the Duwamish River. Progressive dredging and filling created Harbor Island, the West Waterway, and a peninsula area (now known as Terminal 5) near the present location of the Site. The West Waterway and a defined upland peninsula near the Site were completed in 1917. The Lockheed West Site was developed beginning in 1942 by dredging the intertidal areas located on the northern terminus of the current Port Terminal 5. Multiple dredging events were completed to create working space for dry docks and vessel moorage. Several pier structures were constructed over time as part of the shipyard development. Figure 2-2 illustrates Site development, dredging, and filling history.

Shipyard activities at the Site began during World War II. A moorage pier south of the Site along the West Waterway is visible in a 1946 aerial photograph (Figure 2-3), along with extensive

wood treatment and export operations at the current PSR site to the west. During the 1940s and 1950s, dredging was performed to construct dry docks. These dredge and fill events, as well as others, extended the former shipyard uplands site to the north (refer to Figure 2-2).

By 1942, the Lockheed West Site was operated by Puget Sound Bridge and Dredge Company, a predecessor of Puget Sound Bridge and Drydock Company. Puget Sound Bridge and Dredge Company obtained permits for the dredging of the eastern portion of the Lockheed West Site and the West Waterway to allow sufficient depth for dry docks in this area. The dredged material was permitted for disposal on the adjacent tide flats in 1952 and 1954. These dredge and fill events, as well as others, extended the Lockheed West uplands site to the north. Figure 2-4 shows the shoreline expansion based on a 1960 historical aerial photo as well as the areas where material was dredged and filled at or near the Lockheed West Site.

The Puget Sound Bridge and Drydock Company was purchased by the Lockheed Shipbuilding and Construction Company in 1959. During the 1960s, construction of piers along the northern portion of the Site (Piers 21 through 24) occurred from east to west. Until the mid-1960s, the Lockheed West Site was bounded on the west by a major inlet and tidal area used to store logs for the PSR site and probably other wood-processing operations. This inlet was substantially filled for expansion of Terminal 5 by 1965. A 1969 aerial photograph (Figure 2-5) shows the shipyard piers and dry docks. This photograph shows that a small portion of Terminal 5 had not been filled.

In the 1970s and 1980, former shipyard use included ship berthing, repair, and maintenance at three dry docks (two owned by the U.S. Navy and one owned by Lockheed Martin), moorage along the piers, construction in the shipway, and associated upland activities (Figures 2-6 and 2-7). Lockheed Martin discontinued operations at the Site in 1987 after approximately 45 years of continuous operations by Lockheed Martin or its predecessors that included shipbuilding, ship repair, and ship maintenance. The Port purchased the Lockheed Martin shipyard property in 1988 and conducted remediation of the uplands part of the Terminal 5 expansion in the latter half of the 1990s. A 2002 aerial photograph (Figure 2-8) shows the existing pier and shipway configuration.

2.1.3 Historical Shipyard Activities

The Site primarily served as a ship repair, maintenance, and new ship construction facility. Shipyard activities included sandblasting. Sandblasting occurred as part of routine dry dock, pierside, and shipway maintenance operations over many years. Blast grit was reported to cover the upland area near the shipway to a depth of 0.5 foot or more. The historical shipyard included five major piers, dry docks, and a shipway.

Historically, the former shipyard uplands (currently part of Terminal 5) included areas used for sheet metal fabrication, pipe shops, and substations; various repair and storage buildings; diesel fuel tanks and automobile shop; hazardous waste storage areas; and paint and sandblast facilities.

The dry docks and shipway were used to repair, sandblast, and paint vessels. The shipway and Pier 21 and Pier 22 dry docks in particular were major work areas that were subject to accumulation of spent sandblast grit.

2.1.4 Southwest Harbor Project and Terminal 5 Development

In the early 1990s, the Port proposed to complete major upgrades to Terminal 5 as part of comprehensive redevelopment for the SWHP. Proposed activities for the SWHP are described in the 1994 environmental impact statement (Parametrix, 1994a). Part of the proposal included constructing new 400- and 1,000-foot-long pier extensions in the West Waterway. The 1994 environmental impact statement described the use of gasoline, diesel, and lubricating oils that led to areas of petroleum hydrocarbon contamination in the upland areas associated with the former Lockheed Shipyard No. 2. In addition, elevated concentrations of polycyclic aromatic hydrocarbons (PAHs), PCBs, metals, and petroleum hydrocarbons were found in sediments from former catch basins in upland areas (Tetra Tech, 1988).

The Port completed extensive redevelopment and environmental remediation of upland areas at Terminal 5 in the late 1990s. Section 3.2.1 describes remediation activities related to the Terminal 5 expansion.

Following the approval of the SWHP environmental impact statement, the Port completed additional upland improvements to the Terminal 5 area, constructed one new berth, and completed the 400-foot-long pier extension south of the Lockheed West aquatic lease area.

2.2 ENVIRONMENTAL SETTING

This section presents general information regarding the environmental setting for the Lockheed West Site and surrounding vicinity. Shoreline characteristics and land use, the Duwamish/Green River watershed; Site bathymetry; geology and hydrogeology; sediment characteristics; currents, tides, and winds; ecological habitats and biological communities; human uses of the Site; and future Site use assumptions are discussed in this section.

2.2.1 Shoreline Characteristics and Land Use

Elliott Bay and the Duwamish Waterway are shorelines of statewide significance under the Shoreline Management Act and the Coastal Zone Management Program. They are part of Puget Sound, an estuary of national significance under the National Estuary Program.

The Duwamish Estuary and Elliott Bay have experienced extensive development and urban growth during the 20th century. Dredging of the Duwamish Waterway, completed in 1921, resulted in straightening what was originally 9.3 miles of meandering estuarine channel habitat into the 5.3-mile deep-draft channel that exists today. Tidal flats and marshes that once dominated the mouth of the river were dredged and filled to form Harbor Island and the upland areas of the Site. Currently, less than 2 percent of the original flats, shallows, and tidal marshes remain.

The Duwamish Waterway is part of the larger south Seattle/Duwamish industrial district, the oldest of three industrial zones in the greater Seattle area. The Duwamish industrial district is a major transportation corridor for rail, trucking, and waterborne shipping. The primary land uses in the vicinity of the Lockheed West Site have been industrial and maritime-related for over 100 years. Warehousing, commercial, and industrial distribution activities are located throughout the area.

Currently, the upland areas adjacent to the Lockheed West Site are used by the Port for shipping container storage. Occasionally, barges are temporarily moored along the existing pier structures using tug boats. In addition, non-commercial vessel traffic such as recreational boats may pass through the Site. Commercial vessels operating in the vicinity of the Site are controlled by the U.S. Coast Guard and are required to use the established navigational channels and berth approaches.

The shoreline of the former shipyard is characterized by armoring or bulkheads with the exception of a small intertidal beach located on West Waterway. Foot access to the shoreline, piers, and aquatic areas of the Lockheed West Site is controlled by the Port with fencing and locked gates; the shoreline can be accessed by boat traffic. During redevelopment of the upland container facilities for Terminal 5, the Port constructed a sheet pile bulkhead across the apron of the former shipway in the western portion of the Site (refer to Figure 2-8). The shoreline consists of areas of open slope, riprap-reinforcement, and wooden or steel retaining walls in generally poor condition. Since closure of the shipyard, the Port has demolished Piers 21 and 22. In addition, the decking has been removed from Piers 23 and 24 (refer to Figure 2-8).

To the west of the Lockheed West Site is the PSR Marine Sediment Unit. The PSR Upland OU is located immediately to the west of the former shipyard uplands and is currently owned by the Port (south of the inner harbor line). A public access area, including a public observation tower and walkway, was constructed in a portion of the PSR Upland OU. The public access area lies on property owned by the Port and the state of Washington. The remaining portion of the PSR Upland OU was completed as part of a larger intermodal terminal and is currently being leased (see Section 3.0, Figure 3-1). The PSR site use is anticipated to remain industrial in the foreseeable future (EPA, 2004a).

Land use to the south of the Lockheed West Site is primarily industrial. Nucor Steel (formerly named Birmingham Steel, Salmon Bay Steel, and Seattle Steel), located about 0.75 mile to the southwest, between SW Spokane Street and SW Andover Street, is the largest industrial facility in the area. The Nucor Steel property is used for open scrap storage and slag (an inorganic by-product of steel production) processing. There are also Burlington Northern rail lines south of the Lockheed West Site. To the southwest of the Site, between West Marginal Way SW and SW Spokane Street, are relatively small parcels that support various retail and commercial facilities (see Section 3.0, Figure 3-1).

The Lower Duwamish Waterway and southern Elliott Bay provide recreational opportunities for area residents. Numerous boat ramps, parks, waterfront trails, public moorages, and open-space areas provide the public with access to the shoreline. The Lower Duwamish Waterway and

Elliott Bay are also “usual and accustomed” tribal (e.g., Muckleshoot and Suquamish) fishing areas.

Upland areas of West Seattle (located west of the Site) include single-family residential areas. Also to the west, along Harbor Avenue SW, are bluffs that are part of the Duwamish Head Greenbelt, consisting of approximately 343 acres of developed, publicly owned land, and undeveloped or privately owned land. Commercial land uses and park land are located along the shoreline of Elliott Bay to Duwamish Head.

Executive Order 12898, Federal Action to Address Evnironmental Justic in Minority Populations and Low-Income Populations (1994), specifies that “each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States.” EPA provides government-to-government consultation with the Suquamish and Muckleshoot Tribes, review of draft project documents, and use of the Tribal Risk Framework (2007) for tribal consumption rates in the human health risk assessment. In addition, a disproportionate adverse impact assessment as part of an environmental justice analysis is being conducted by EPA’s Environmental Justice office for a nearby cleanup site. The results of this analysis could impact EPA’s decisions for the Lockheed West site cleanup, and will be reviewed.

2.2.2 Duwamish/Green River Watershed

The West Waterway is at the mouth of the Duwamish/Green River system, which drains an area of about 483 square miles (Grette and Salo, 1986). The upper drainage is fed by rain and snowmelt, while the lower drainage and two main tributaries, Big Soos Creek and Newaukum Creek, are fed by rain and groundwater. Flows in the main river below river mile (RM) 64.5 are controlled by releases from Howard A. Hanson Dam and the City of Tacoma water diversion at RM 61. The U.S. Army Corps of Engineers (USACE) has limited discharges to 12,000 cubic feet per second (cfs) at the city of Tukwila and minimum flows to as low as 200 cfs, with an average flow of 1,500 to 1,800 cfs (Weston, 1993).

The West Waterway carries most of the river flow due to shoaling at the entrance of the East Waterway (USACE, 1983). There is also contributing flow from Longfellow Creek that

discharges into the head of the West Waterway (refer to Figure 1-1). The Longfellow Creek watershed is the second largest in Seattle (City of Seattle, 2008), covering 1,729 acres with 4.6 miles of water course length. It flows through the Delridge Valley. The water course includes 3.9 miles of main channel, one-third of which is piped, and 0.7 mile of tributaries.

2.2.3 Shoreline and Aquatic Area Bathymetry

A bathymetry survey of the Lockheed West Site was conducted on May 20, 2006, and the results were included in the *RI/FS Work Plan*. The results are shown on Figure 2-9.

The Site is located in a transition zone between estuarine and marine environments. Intertidal habitat is affected by relatively low-salinity water from the Duwamish River that forms an approximate 3- to 6-foot layer over denser saline waters. There is an apparent upwelling effect of marine waters toward the northern edge of the Site to the west, toward Duwamish Head (Sillcox et al., 1981).

The aquatic area of Lockheed West is situated on a relatively flat bathymetric bench with elevations varying between about +14 to -40 feet MLLW. Underwater slopes continue to the north at a gradient ranging from about 5 horizontal to 1 vertical to 2 horizontal to 1 vertical.

As discussed in Section 2.2.1, shoreline areas of the Site include open, exposed slopes with sand and gravel, a new interlocking sheetpile bulkhead across the former shipway, and older retaining walls and riprap-reinforced areas. Exposed shoreline areas have relatively steep slopes. Intertidal areas contain scattered debris and gravel near the shoreline. Sandy surficial sediments in the subtidal areas contain less gravel and debris.

Debris piles of amalgamated sandblast grit and slag are also locally present in the intertidal area. There are also historical piers and a shipway that were associated with the operations of the former shipyard. Many pilings remain in place at the shipway and pier locations. The shoreline to the east consists of areas of open slope, riprap-reinforcement, and wooden or steel retaining walls in generally poor condition. Since closure of the shipyard, the Port has demolished Piers 21 and 22 and removed the decking from Piers 23 and 24 (refer to Figure 2-8). Numerous apparent debris piles and multiple pilings are observed in the subtidal areas of the former dry docks (refer to Figure 2-9).

2.2.4 Geology and Hydrogeology

Prior to the 20th century, the Duwamish River delta near the Site consisted of an estuary of shallow, meandering channels, marshland, and tidal mudflats. During the 20th century, the Duwamish River channel was straightened, and the marshes and mud/sand intertidal substrates at the mouth of the river were filled. Geologic cross-sections, based on soil borings installed in offshore and upland portions of the Site, indicate the presence of four distinct geological units under and surrounding the Lockheed West Site (DNR, 1999). These units are described as follows (in sequence from the soil/sediment interface downward):

- **Upland Fill**. The soil unit underlying the present upland configuration consists of an approximate 20-foot-thick layer of medium dense fill material containing varying amounts of sand, silt, and clay. Review of historical dredging permits indicates the source of this fill to be material previously dredged from areas within the West Waterway of the Duwamish River (adjacent to and within the Site).
- **Recent Sediment Deposits.** The upper offshore geological unit comprises a veneer of soft, organic silt and sand deposited at the Site after completion of historical dredging activities.
- **Post-Glacial Deposits.** Underlying the recent sediment deposits is a post-glacial unit comprising soft, organic silt ranging from approximately 3 to 7 feet in thickness. Below the surface silt layer are sands with interbedded thin silt layers. This post-glacial unit ranges from approximately 100 to greater than 155 feet in thickness. This deposit is likely the result of estuarine deposition from the Duwamish River.
- **Glacial Deposits.** A unit of hard sandy silt was observed in the two southernmost portions of the offshore area of the Site. This unit is a glacially overridden deposit and was encountered at elevations of approximately -60 to -140 feet MLLW. This unit is assumed to slope downward into the Site toward Elliott Bay.

Groundwater flow is tidally influenced. Groundwater flowing northward from the adjacent upland areas discharges to Elliott Bay at elevations of about -40 feet MLLW and above. At low tide, groundwater may discharge to surface waters of Elliott Bay through intertidal seeps. Shallow groundwater flow is generally toward Elliot Bay and the West Waterway based on recent tidal studies for SWHP and the PSR site (Aspect, 2005; RETEC, 2004, 2005a, 2006).

Two hydrogeologic zones were identified and characterized during the SWHP (Aspect, 2005)—a shallow Fill Aquifer and a deeper Estuarine Aquifer. The Fill Aquifer occurs in various fill materials that range from 20 to 40 feet in thickness.

Sandy silt to silty fine sand tide-flat deposits, typically 1 to 10 feet in thickness, occur over most of the SWHP area with the exception of the easternmost portion nearest the West Waterway. The occurrence of this low permeability layer can result in locally confined conditions in the Estuarine Aquifer. The Estuarine Aquifer zone is underlain by a lower permeability unit that occurs at depths ranging from 30 to 50 feet below ground surface (bgs).

The western portion of the Lockheed West aquatic area and adjacent shoreline may be influenced by groundwater flow from the upland areas of the adjoining PSR site. Groundwater flow before implementation of the PSR slurry wall remedy (see Section 3.2.2) had a component of groundwater flow to the northeast toward the Lockheed West Site. More recently, there was some evidence of groundwater flow around the eastern end of the PSR slurry wall and toward the Lockheed West Site (EPA, 2004a).

2.2.5 Sediment Characteristics

Sediment sampling and drilling data from Site exploration by Hart Crowser in 1995 indicate the presence of soft organic silt commonly extending from the surface to depths of about 3 to 7 feet below the mudline. These sediments represent the majority of materials affected by historical contaminants at the former shipyard. Other investigations (e.g., Port of Seattle, 1994) describe the uppermost sediments as sand with varying amounts of gravel and silt. The uppermost sediments are underlain by interbedded sands and silts of alluvial origin from the deltaic environment of the Duwamish River or fill derived from these materials. Alluvial sands and gravels extend to depths of 100 feet or more below mudline and have varying densities. Individual layers of silt, sand, and gravel are laterally discontinuous and do not have obvious physical characteristics that produce preferential pathways for groundwater flow or contaminant migration. Contacts between units are not distinct and suggest variations in depositional environment or filling. Information on the subsurface sediments of the Lockheed West Site is derived from investigations previously conducted and summarized in the environmental impact statement and Aquatic RI for the SWHP (Parametrix, 1994b,c). Two geotechnical investigations

were completed in and around the Site prior to the Lockheed West RI, including characterization of sediment moisture content, sediment classifications, and gradational and shear strength properties (Enviros, 1990; Hart Crowser, 1995).

Information regarding sediment transport dynamics (e.g., sediment loading, sediment mixing rates, effects of ship-induced scour, historical dredge depths) is discussed in Section 6.0 of this document.

2.2.6 Currents, Tides, and Wave Influences

The semidiurnal tides in the Duwamish River estuary have marked inequalities in the successive high- or low-water stages. Based on a tide reference station approximately 1 mile from the mouth of the estuary, the mean tide stage is 6.5 feet above MLLW and maximum and minimum estimated stages are 15.0 feet ± 0.5 foot above MLLW and 4.5 feet ± 0.5 foot below MLLW, respectively (King County DNR, 2001). Circulation of water in the Duwamish estuary is a function of river flows and the movement of saltwater upstream during tidal cycles. The intrusion of saltwater into the river creates a saltwater wedge overlain by freshwater that extends as far as 10 miles upstream (Ebbesmeyer et al., 1998).

Physical properties of the waters of the Site are similar to salinity and current patterns in inner Elliott Bay. Both are affected by the interaction of tidal flows and outflow from the Duwamish River. Circulation and salinity distribution in the inner bay were investigated by the National Oceanic and Atmospheric Administration (NOAA; Sillcox et al., 1981). The general circulation pattern in the inner bay is counterclockwise, with Duwamish River flows discharging to the bay. This pattern can create eddies at the mouth of West Waterway during high river flows and ebb tides. During flood tides with low river flow, long shore currents are reported to be in the range of 0.2 foot per second (ft/sec; 6 centimeters per second [cm/sec]). West Waterway flows reach as high as 1.4 ft/sec (43 cm/sec) just below the water surface. The combination of tidal and river flows results in a consistent flow across the Site from west to east. Wind-driven circulation will eventually upset this circulation pattern, but east winds are not frequent or strong enough to reverse the overall circulation pattern. Current meters placed at depths in excess of 100 meters showed that current velocities in the bay were too low to re-suspend sediments (Sillcox et al.

1981). However, localized wind-driven currents may be sufficient to re-suspend sediments in the shallow areas. Wind-induced re-suspension was not investigated by NOAA.

A coastal engineering analysis was conducted by Coast and Harbor Engineering, Inc., in 2004 in support of sediment remediation efforts at the Lockheed Shipyard No. 1, which is representative of conditions at the Lockheed West Site. Wind speed and direction data were derived from the National Data Buoy Center C-MAN Station WPOW1 at West Point Washington, collected from 1984 through 2001. The Site is open to direct wind-wave impacts from primarily the north and northwest. Of these, wind from the northwest is estimated to be critical for the wind-generated wave conditions (CHE, 2004). Wind data, in combination with bathymetry data derived from NOAA (1930 to 1999) and the USACE (2004), were used to hindcast (i.e., predict previous) wave conditions in the vicinity of the Site. Extreme wave heights ranging from 3.6 to 3.9 feet are expected to occur every 5 to 10 years, respectively, with larger waves (4.4 feet to 4.7 feet) occurring at intervals of 25 years or greater. Wind-wave heights, periods, and directions are strongly affected by local Site features, with the most extreme wave heights occurring in Elliott Bay and declining toward the south (away from Elliott Bay) in the West Waterway (CHE, 2004).

A sediment transport analysis was completed by URS (2002) as part of the PSR Marine Sediment Unit cap design. The sediment transport analysis included collection of bottom current speed and direction data at two locations in the Marine Sediment Unit. Mean current speeds were measured to be in the range of 0.07 to 0.1 ft/sec (2 to 3 cm/sec) and 99.9 percent of measured current speeds were 0.4 ft/sec (12 cm/sec) or less. Annual wind data were analyzed to identify potential correlations with the observed current speeds. No correlation was identified; however, the analysis concluded that there is no indication that significant bottom currents would be induced at the Marine Sediment Unit during storm events. A screening-level analysis was used to assess the need for restrictions on sediment grain size to resist erosion in subtidal areas of the Marine Sediment Unit. This analysis concluded that the fine-grained cap materials placed at the Marine Sediment Unit would be stable at current velocities less than 0.7 ft/sec (20 cm/sec).

2.2.7 Ecological Habitats and Biological Communities

The aquatic environment at the Lockheed West Site consists of estuarine waters and sediments. As mentioned above, most of the shoreline of the former shipyard is characterized by armoring

or bulkheads, typical of the industrial shoreline in much of the Duwamish Waterway. Benthic habitats include intertidal habitat (exposed by low tides) and subtidal habitat (never exposed by low tides). Intertidal habitat at the Site consists of about 2 acres located on West Waterway, with subtidal habitat making up the remaining area. Taylor et al. (1999) mentions the presence of a wide range of habitat types in the area, including a sandy pocket beach, cobble beach, boulders, riprap, and pilings. Much of the subtidal habitat has been dredged at various times in the past, in both the north (Elliott Bay) and east (West Waterway) areas of the Site (Tetra Tech, 2008a). The east subtidal habitat includes part of the deeper navigation channel of the West Waterway.

The Duwamish Waterway is characterized by a saltwater wedge that originates in Elliott Bay and moves up and down the waterway. The toe of this saltwater wedge is always located upstream of the Lockheed West Site in the Lower Duwamish Waterway, even during ebb tides and high-flow conditions in the Duwamish River (Stoner et al., 1975). This saltwater wedge makes the sediment and bottom water column on the east portion of the Site that lies in the West Waterway estuarine in nature.

Flora and fauna of the aquatic area and shoreline include a typical mix of invertebrates and algal plants found in Elliot Bay and similar environments of Puget Sound with a history of industrial use. Bivalves, crustaceans, and several species of worms are found in the fine sediments. Crustaceans and mollusks are typically found in coarser sediments. The environment also reportedly supports birds, crabs, resident fish (e.g., perch, sculpins, rockfish), as well as anadromous fish. This assemblage of species is fairly typical of marine and shoreline communities representative of shallow areas of Elliott Bay and Puget Sound with modified or disturbed shoreline features.

2.2.8 Future Site Use Assumptions

Future plans for the Site are uncertain; however, potential future Port plans (discussed earlier) and tribal fishing and shellfish harvesting are considered in the risk assessments to establish remedial action objectives and in the development and evaluation of remedial alternatives. As discussed above, in the early 1990s, the Port proposed to complete major upgrades to Terminal 5 as part of the SWHP. Proposed activities for the SWHP are described in the 1994 environmental impact statement (Parametrix, 1994a). Part of the proposal included constructing new 400- and

1,000-foot-long pier extensions in the West Waterway south of Pier 21 and dredging additional berths. The proposed 1,000-foot pier extension and dredging of a second berth described in the environmental impact statement have not been completed at the time of this report.

Future plans for developing the second berth and pier extension are uncertain but the Port has expressed continued interest in completing this work. The Port has provided Lockheed Martin schematic drawings of the potential project footprint. Lockheed Martin also understands that the Port may also want to use the northern portion of the Site for temporary barge moorage, with the potential construction of mooring dolphins (i.e., independent groups of pilings used to tie up vessels). Lockheed Martin will consider these plans, to the extent possible, in the evaluation of potential remedial options at the Site (see Section 11).

2.3 LOCKHEED WEST PRELIMINARY CONCEPTUAL SITE MODEL OVERVIEW

The Lockheed West Site preliminary conceptual site model is described in detail in the *RI/FS Work Plan* and presented in Figure 2-10. The general mechanisms by which the sediments adjacent to the former shipyard could have been contaminated include the following:

- Historical shipyard operations/activities;
- Direct discharges from historical shipyard operations into the receiving water (e.g., loss of wastes from floating dry docks);
- Transport and discharge of historic and current stormwater outfalls from adjoining upland areas;
- Transport and discharge of contaminated groundwater from adjoining upland areas;
- Atmospheric deposition from the shipyard; and
- Transport via sediment, water, or air from other sites or activities in the Site vicinity.

Of these mechanisms, historical overwater operations at the former shipyard appear to have been the most significant historical source of sediment contamination. Soils contaminated by historical spills and other environmental releases have a potential pathway to the adjacent aquatic sediments from direct discharge, transfer through stormdrain systems, or groundwater transport. Ongoing transport of contamination in sediment, water, groundwater, and air onto the Site from nearby areas is important from the standpoint of remedy recontamination. Types of potential ongoing sources have been identified and evaluated in the *Source Control Evaluation Report*; the

findings of this effort are summarized in Section 5.0 of this report. Conceptual models for ecological and human health risks are presented and discussed in Section 7.0 of this report. A more comprehensive and refined description of the conceptual site model, based on findings in the RI, is presented in Section 8.0.

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Lockheed West Seattle Superfund Site, Seattle, WA

Figure 2-1
Former Property Boundary Map

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Lockheed West Seattle Superfund Site, Seattle, WA

Figure 2-2
Site Development, Dredging and Filling History

Figure 2-3
1946 Aerial Photograph

Lockheed West Seattle
Superfund Site
Seattle, WA

TETRA TECH

Figure 2-4
1960 Aerial Photograph

Lockheed West Seattle
Superfund Site
Seattle, WA

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Figure 2-5
1969 Aerial Photograph

Lockheed West Seattle
Superfund Site
Seattle, WA

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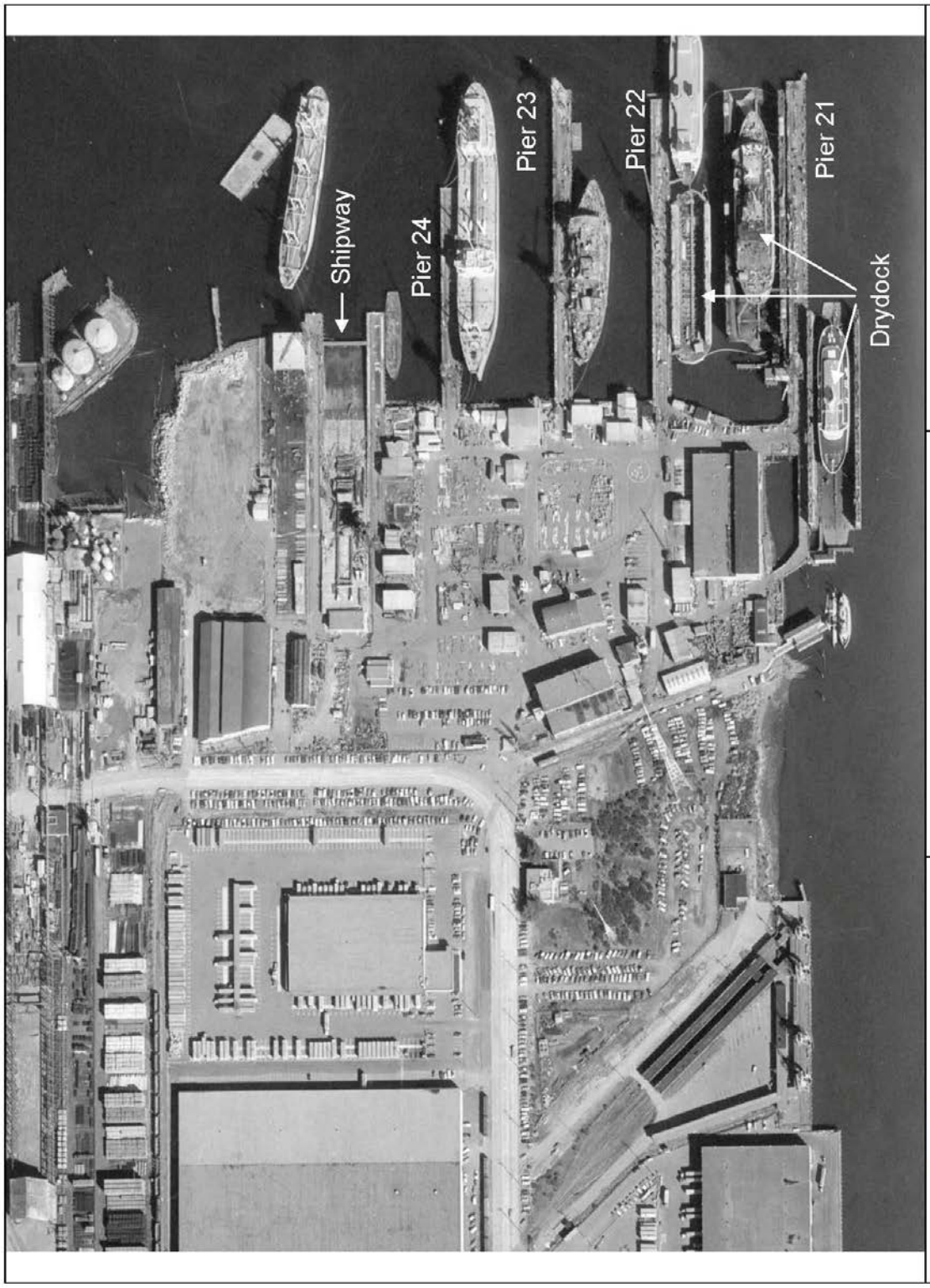

Figure 2-6
1974 Aerial Photograph

Lockheed West Seattle
Superfund Site
Seattle, WA

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Lockheed West Seattle
Superfund Site
Seattle, WA

Figure 2-7
1980 Aerial Photograph

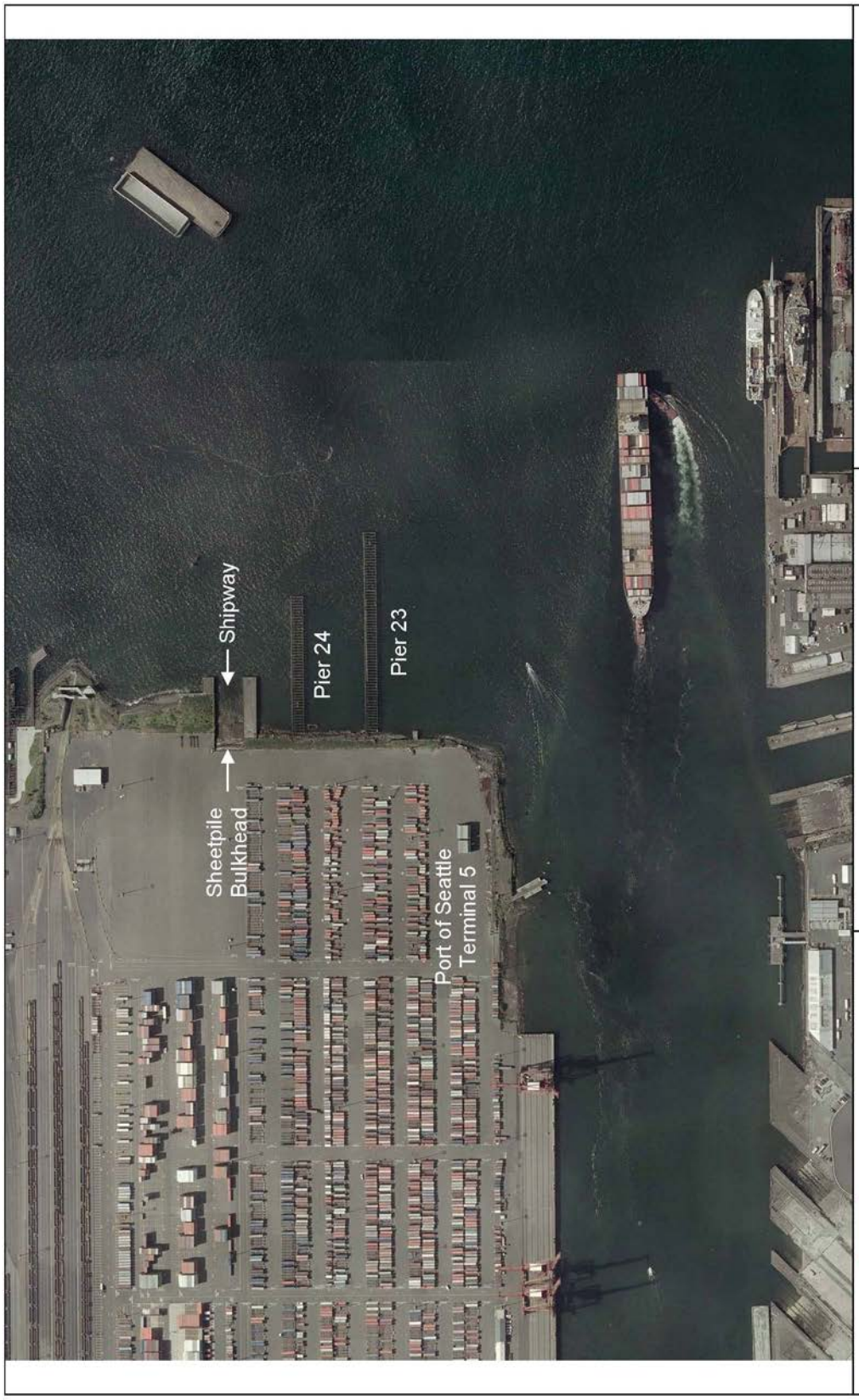

Figure 2-8
2002 Aerial Photograph

Lockheed West Seattle
Superfund Site
Seattle, WA

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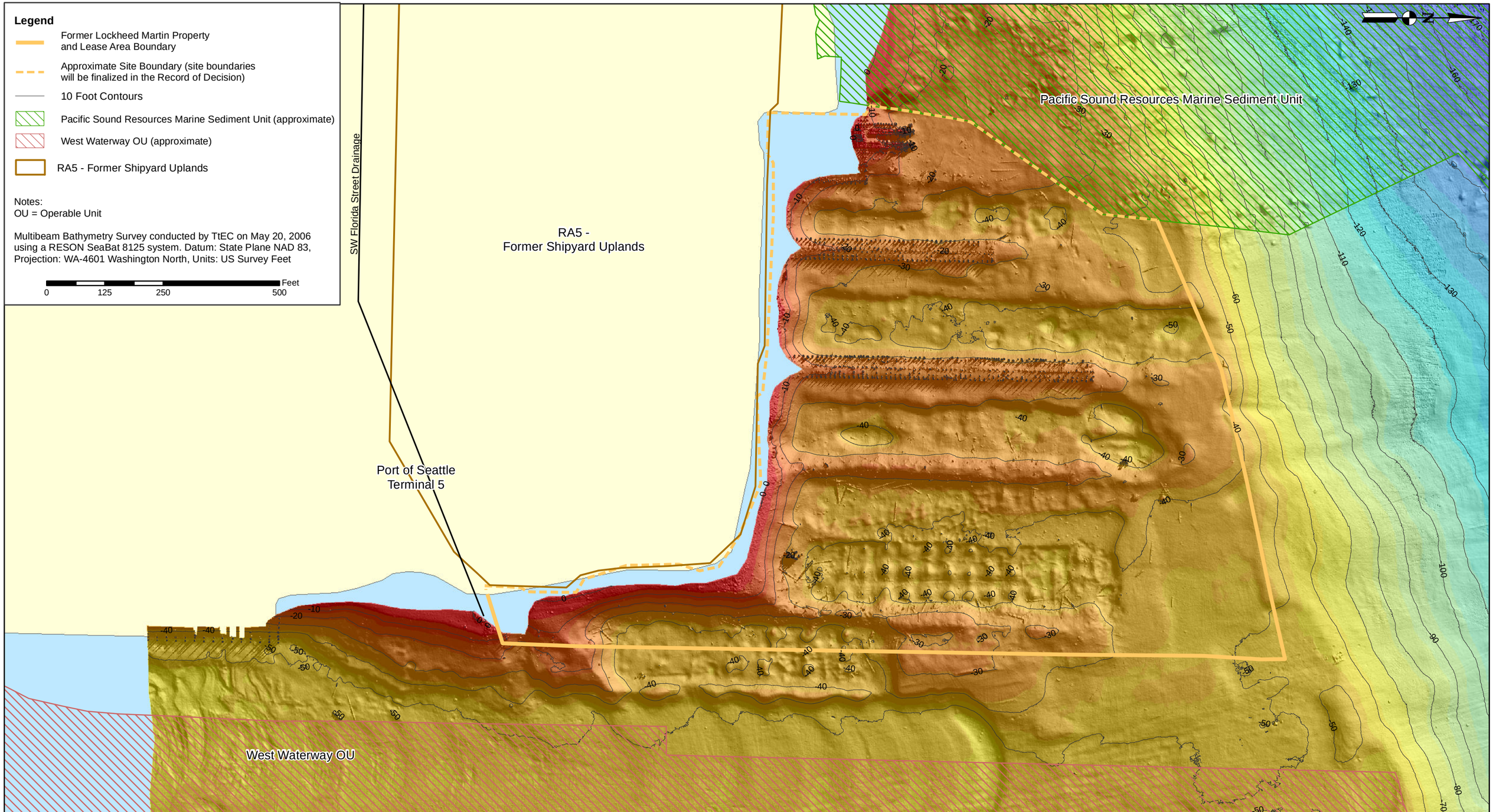

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Lockheed West Seattle Superfund Site, Seattle, WA

Figure 2-9
Lockheed West Site Bathymetry

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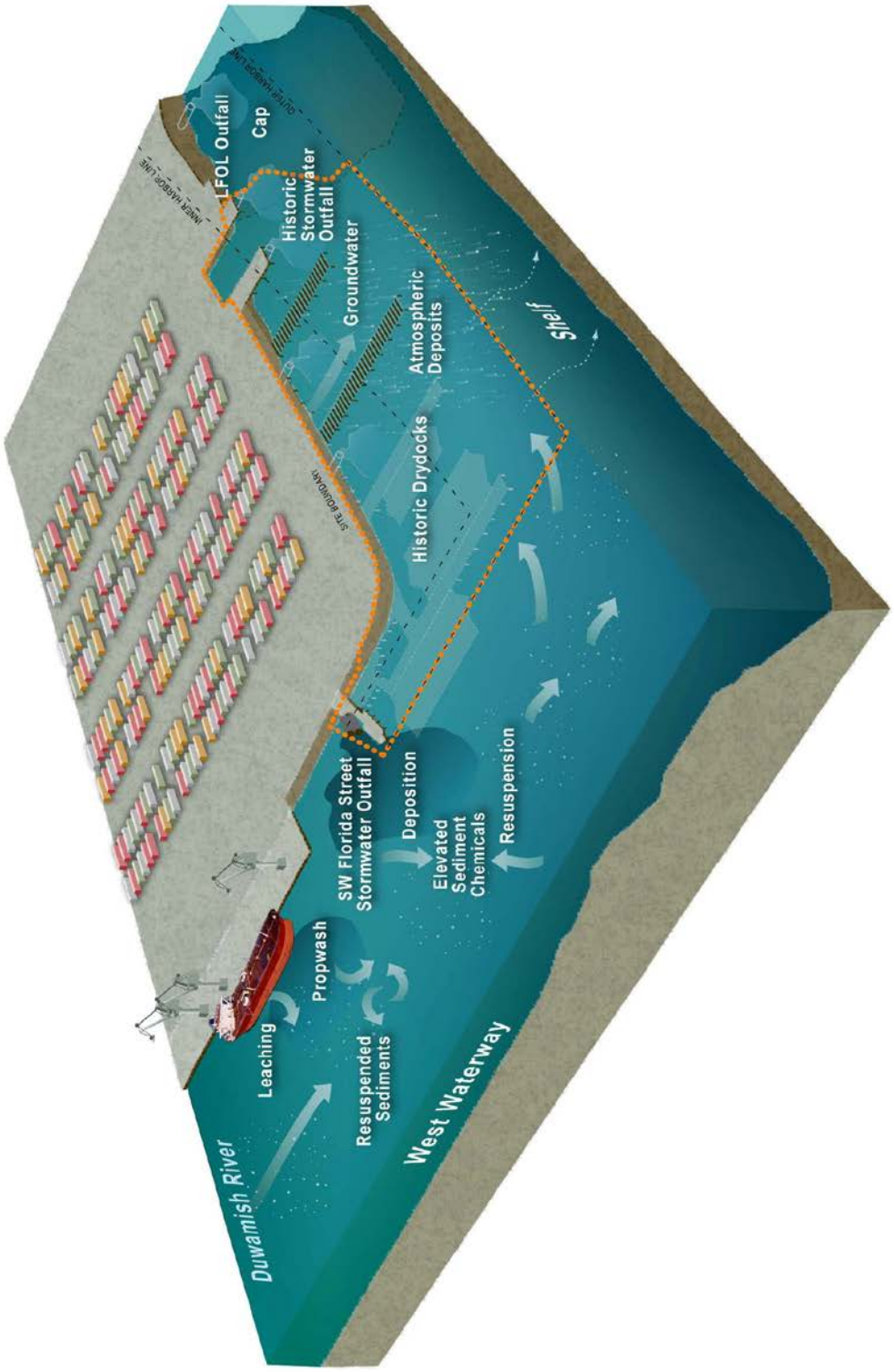

Figure 2-10
Conceptual Site Model

Lockheed West Seattle
Superfund Site
Seattle, WA

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SECTION 3
Summary of Previous Investigations and Remediation Activities

This section summarizes the pre-RI Site investigations and remedial activities that have taken place at or in the immediate vicinity of the Lockheed West Site. Previous Site investigations and associated data are summarized in detail in the *RI/FS Work Plan*. The existing data have served as the initial background for understanding the general conceptual site model, nature and extent of contamination, and identification of data gaps. The recent data collected during the RI have supplemented the existing data and provide contemporaneous and more comprehensive data coverage in support of the evaluation of site risks and the evaluation and selection of remedial alternatives for the Lockheed West Site.

Previous areas of investigation and remediation activities in the vicinity of the Lockheed West Site include both upland contaminated sites and nearby contaminated sediment sites. Figure 3-1 is a general vicinity map showing the locations of nearby environmental cleanups and major discharge features. Detailed information concerning these sites is summarized and evaluated in the *Source Control Information and Data Gap Report* and the *Source Control Evaluation Report* prepared in support of the Lockheed West RI/FS work effort. These two reports are intended to work together and specifically cover the topic of source control (see Section 5.0).

3.1 PREVIOUS LOCKHEED WEST SEDIMENT-RELATED INVESTIGATIONS

Since 1984, an extensive series of studies have been independently conducted by Lockheed Martin and the Port in an effort to determine the nature and extent of sediment contamination in the Lockheed West Site and vicinity (Tetra Tech, 2008a). Much of this information was compiled by Parametrix (1994b,c) and by Enviros (1990) to support characterization of the Lockheed Shipyard No. 2 site for the SWHP. Available historical sediment quality information

in the vicinity of the Lockheed West Site includes samples collected prior to 1998 and those collected in 2003 by Hart Crowser as part of the former Lockheed Shipyard No. 2 due diligence investigation (Hart Crowser, 2003). Previous work also supported studies for the Harbor Island RI/FS (Weston, 1993), evaluation of sediments in the West Waterway of the Duwamish River, and other sediment quality evaluations. Historical and recent sample locations are shown on Figure 3-2.

Environmental samples from this historical work are summarized in Appendix A of the *RI/FS Work Plan* and were compiled from the Ecology SEDQUAL database and Hart Crowser (2003). In addition to bulk chemical analysis, sediment characterization work also included the following tests for some of the samples collected:

- Nineteen bioassay tests;
- Eight infauna sampling locations;
- Five surface samples tested using the Toxicity Characteristic Leaching Procedure (TCLP);
- Forty benthic flux samples from two locations; and
- Sixty interstitial porewater samples from six squeeze core locations.

Hart Crowser (1995) also completed 24 additional subsurface geotechnical borings for the Port to assess sediment types and physical properties throughout the Lockheed West Site and the adjacent West Waterway (Tetra Tech 2008a). Data from these borings were used for engineering design and stability analysis for development of Terminal 5 by the Port.

In addition to the recent sediment data collected in direct support of the Lockheed West RI, data from other sediment investigation efforts have been incorporated in this RI to the extent that the data were found to be valid and usable for the intended purposes. These include data from the following previous studies:

- **Sediment Quality Study in Elliot Bay (Ecology, 2009a).** In 2007, Ecology conducted a sediment quality study in support of the Urban Waters Initiative. This study included collection of surface sediment samples from Elliot Bay, which were analyzed for metals, PCBs, pesticides, semivolatile organic compounds (SVOCs), conventional parameters,

and grain size. The samples for this study were grouped by Ecology into three general categories: Basin, Urban, and Harbor areas.

- **Lockheed Shipyard No. 2 Sediment Characterization (Hart Crowser, 2003)**. Surface sediment samples were collected to update the Site environmental status. Laboratory analyses included metals, PCBs, pesticides, SVOCs, volatile organic compounds (VOCs), dioxins conventional parameters, and grain size.
- **Southwest Harbor Puget Sound Dredge Disposal Analysis–Related Sediment Quality Investigation (Enviros, 1992)**. This investigation included the collection of subsurface sediment core data, which were analyzed for metals, PCBs, pesticides, SVOCs, VOCs, and conventional parameter analysis.
- **Southwest Harbor RI Sediment Quality Investigation (Enviros, 1991)**. Subsurface core data were collected and analyzed for metals, PCBs, SVOCs, VOCs, and conventional parameters.
- **Lockheed Shipyard No. 2 Sediment Characterization and Geochemical Study (Enviros, 1990)**. This study included the collection of sediment core data for metals, PCBs, pesticides, SVOCs, VOCs, and conventional parameters analyses.

The use of the above historic data in the RI evaluation, including assessment of their usability and level of validation, is provided in Section 4.2.6. A brief discussion regarding previous environmental cleanups, including both upland and aquatic contaminated sediment sites in the vicinity of the Lockheed West Site, is provided in the following section.

3.2 NEARBY ENVIRONMENTAL CLEANUPS

Previous investigations and remediation activities in the vicinity of the Lockheed West Site include both upland and aquatic sediment cleanup sites (Figure 3-1). Detailed information concerning these sites is summarized and evaluated in the *Source Control Information and Data Gap Report* and the *Source Control Evaluation Report*.

Environmental cleanups immediately adjacent to the Lockheed West Site include the SWHP to the south, PSR Superfund site to the west, and the West Waterway to the east (Figure 3-1). Given their immediate proximity to the Lockheed West Site, a brief discussion of these nearby cleanup sites is provided in the following sections.

3.2.1 Southwest Harbor Cleanup Project

In the early 1990s, the Port proposed to complete major upgrades to Terminal 5 as part of comprehensive redevelopment for the SWHP. Proposed activities for the SWHP are described in the 1994 EIS (Parametrix, 1994a). The Port completed extensive redevelopment and environmental remediation of upland areas at Terminal 5 in the late 1990s. As part of the purchase agreement between the Port and Lockheed Martin, the Port agreed to remediate both the upland portion of the Site and the aquatic areas where remedial actions were necessary for constructing new Terminal 5 facilities. For undisturbed aquatic areas, Lockheed Martin maintained the primary responsibility for sediment cleanup where contamination resulted from past site activities by the former shipyard (i.e., Lockheed West Site).

There are five remediation areas (RA-1 through RA-5) at and near Terminal 5 where environmental cleanups have been performed as part of the SWHP with Ecology as the lead regulatory agency (Figure 3-1). Remediation activities at the former shipyard uplands related to the Terminal 5 expansion included excavating and removing vadose zone soils and storm drain sediments, paving the majority of the former shipyard area, removing and replacing the existing storm drain system, and monitoring site groundwater.

The former Lockheed Shipyard uplands was designated as remediation area RA-5 in support of the SWHP (Figure 3-1). Results of the prior Site investigations were used during the feasibility study for the Terminal 5 expansion project to identify COCs and cleanup levels. Site-wide COCs were identified (Enviros, 1993) for the uplands area and included specific VOCs (methylene chloride, tetrachloroethene, and trichloroethene), total petroleum hydrocarbons (TPH), specific metals (antimony, arsenic, cadmium, copper, lead, mercury, and nickel), and carcinogenic PAH (cPAH). Contaminated soils in upland areas were excavated and treated in 1994. The former storm drain system was also decommissioned and catch basin sediments were removed. An asphalt cap was placed over the entire site. Long-term monitoring of the former Lockheed Shipyard uplands is being performed by the Port under Ecology supervision as part of the SWHP. A comprehensive discussion of the SWHP, including remedial actions, ongoing long-term monitoring, and current environmental status is provided in the *Source Control Information and Data Gap Report*.

3.2.2 Pacific Sound Resource Superfund Site

The PSR site, formerly known as the Wyckoff West Wood Treating Facility, is a Superfund site located to the west of the Lockheed West Site along the shoreline of Elliott Bay. Wood-treating operations were conducted at the site between 1909 and 1994 (EPA, 1999a). The southern portion of the PSR site was used primarily for treated wood storage and the northern portion of the facility was used for processing. Releases of wood treatment products (primarily creosote and an oil carrier containing other wood-treatment chemicals) over many years created widespread soil and groundwater contamination. Both light non-aqueous phase liquid and dense non-aqueous phase liquid layers were historically present at the site. Contamination from dense non-aqueous phase liquid was present in the deepest boring installed in upland areas of the site (100 feet bgs). The COCs identified for the former wood treating facility include PAHs, pentachlorophenol (PCP), zinc, PCBs, and dioxin/furans.

Cleanup and monitoring activities at the PSR site are being performed under CERCLA. The site was divided into two OUs for the cleanup: the upland unit and the Marine Sediment Unit. The 1999 ROD (EPA, 1999a) addresses both units. For the upland unit, the cleanup actions that were completed include the following: demolition of all on-site structures; source material removal (highly contaminated oil and sludge); non-aqueous phase liquid containment using a shallow recovery trench with disposal; and construction of a low-permeability cap and slurry wall. For the Marine Sediment Unit, the ROD required that the sediments be capped with limited dredging such that all areas with sediment contamination above the sediment management standards were addressed. The ROD requires that all capped areas remain at or below the sediment quality standards (SQS) levels for all contaminants. The remedial action for the sediments was completed in February 2005. Ongoing work includes long-term monitoring and the EPA's evaluation of chemical monitoring data for the PSR cap in relation to Urban background, natural background, and risk-based threshold concentrations (RBTCs). This evaluation will be used to evaluate long-term recontamination and systemwide equibrium levels that will in turn be used to determine long-term performance and operations, maintenance and monitoring plan (OMMP) criteria.

As noted in *RI/FS Work Plan*, a portion of the contaminated sediments within the Lockheed West Site was addressed as part of the PSR remediation. A sediment cap was placed in the

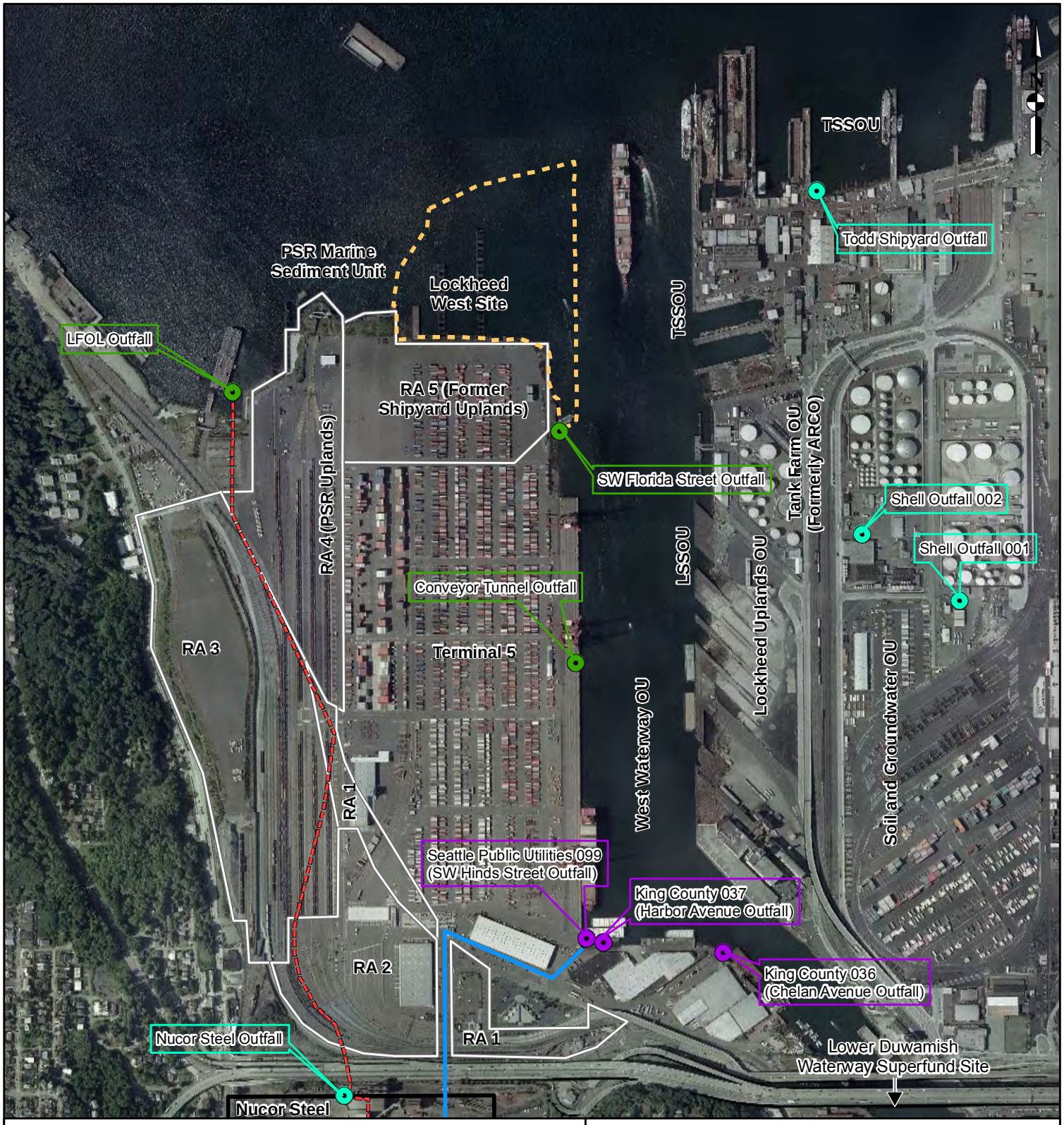
southwest part of the Site adjacent to the former shipway. A more detailed discussion regarding Superfund site cleanup, including remedial actions, ongoing long-term monitoring, and current environmental status, is included in the *Source Control Information and Data Gap Report*

3.2.3 West Waterway OU

The West Waterway OU is located in the West Waterway at the mouth of the Duwamish River estuary near Harbor Island and adjacent to the Lockheed West Site (Figure 3-1), and consists of approximately 70 acres of marine sediments. The West Waterway is a dredged navigable channel used extensively for industrial purposes. The waterway consists primarily of subtidal sediments. The shoreline of the West Waterway is predominantly pilings, bulkhead, and riprap. There are very few areas of intertidal sediments along the shorelines adjacent to the West Waterway OU.

In 1999, the EPA determined that a no-further-action was appropriate for the marine sediments in the West Waterway. EPA stated that a no-action decision was appropriate because environmental investigations and site-specific risk assessments led to the conclusion that concentrations of chemicals (including PCBs, tributyltin [TBT], and mercury) in marine sediments within the West Waterway OU do not pose unacceptable risks to human health and the environment. Further, environmental investigations did not identify any “hot spots” of contaminated sediments that warranted cleanup. The EPA stated that sediments with the highest concentrations of chemicals on the western side of Harbor Island are already being cleaned up under the EPA ROD for the “Shipyard Sediment” (Todd and Lockheed Shipyards). Finally, EPA stated that the majority of the contamination associated with the Harbor Island site, including contamination that could have contributed to sediment problems in the West Waterway OU, is being addressed as part of the shipyard sediment cleanups, upland soil and groundwater cleanups, and upland source cleanups implemented to reduce contaminant inputs into the marine environment. The EPA stated that all actions necessary to control contaminant releases from the uplands portion of the site to adjacent sediments in the West Waterway OU have been completed or will be addressed through ongoing actions. The EPA is further evaluating the chemical monitoring results for the West Waterway and Harbor Island shipyards of LSSOU and TSSOU.

As part of the RI/FS and supplemental investigations, EPA conducted risk assessments to evaluate the current and future effects of contaminants on human health and the environment. A No Action ROD was signed in 2003 (EPA, 2003a) based on the risk assessments.



Legend

RA = Southwest Harbor Remediation Area
PSR = Pacific Sound Resources
LSSOU = Lockheed Shipyard Sediment OU
TSSOU = Todd Shipyard Sediment OU
NDPES = National Pollutant Discharge Elimination System
CSO = Combined Sewer Overflow
LFOL = Longfellow Overflow Line
OU = Operabe Unit

Approximate Site Boundary: Site boundaries will be finalized in the Record of Decision.
Remedial Action Areas
Longfellow Overflow Line
Longfellow Creek

Outfall Type

CSO
Other Drainage Feature
NDPES Permitted Discharge

Figure 3-1 Nearby Environmental Cleanups and Major Discharge Features General Vicinity Map

0 500 1,000
Feet

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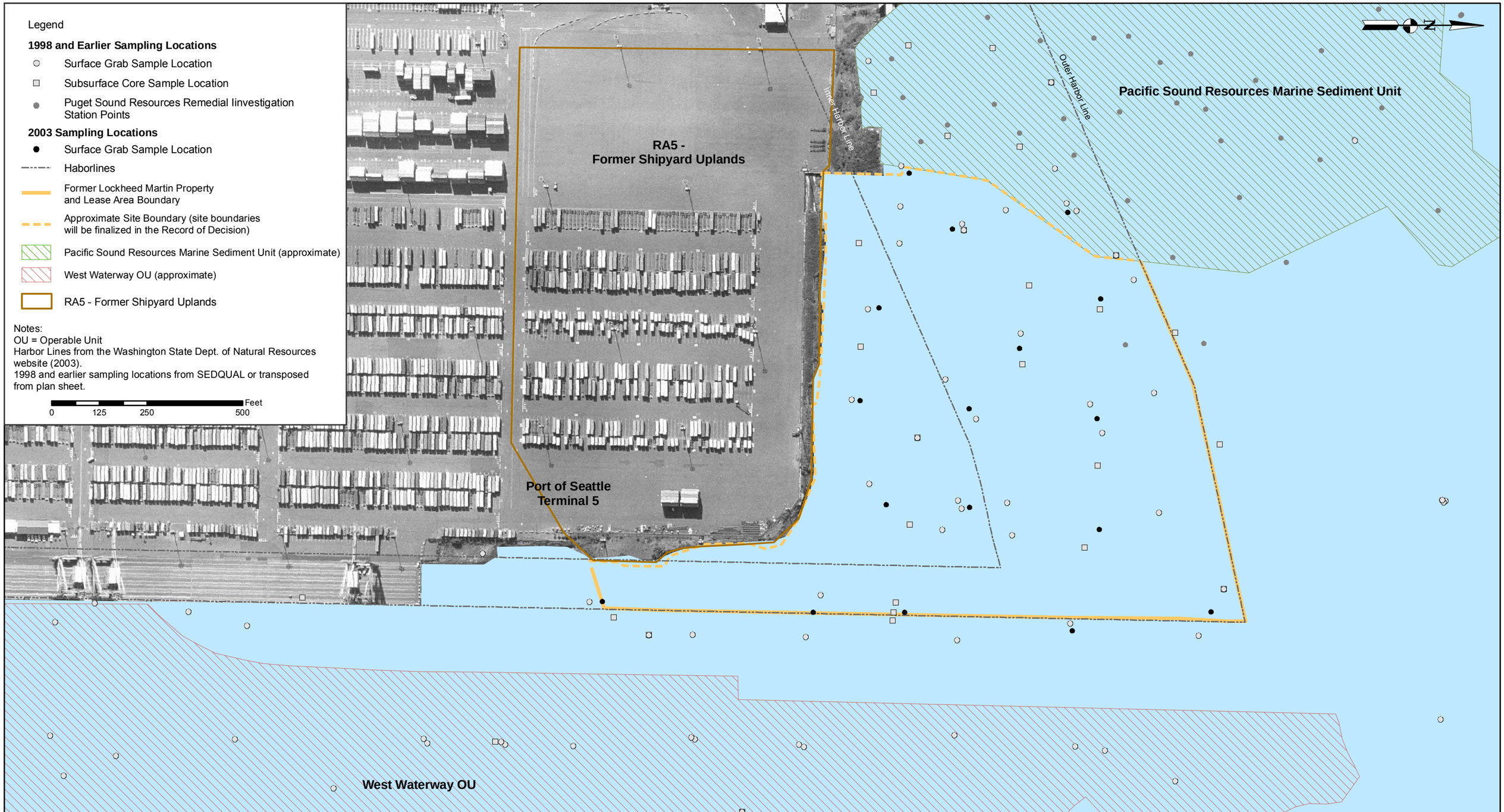

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Lockheed West Seattle Superfund Site, Seattle, WA

Figure 3-2
Summary of Pre-Remedial Investigation Sediment Sample Locations

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SECTION 4
Nature and Extent of Contamination

This section presents a summary of the nature and extent of the contamination at the Lockheed West Site based on the data collected for the surface and subsurface sediment, porewater, and clam tissue samples. Section 4.1 summarizes the data gaps identified in the work plan. Section 4.2 summarizes the field activities, data collection methods, laboratory analysis, data review, and data reduction procedures for use in the RI. Section 4.3 summarizes the results of the physical characterization activities (i.e., bathymetric and topographic surveys and shoreline survey). Section 4.4 summarizes the sediment physical characteristics for grain size and geotechnical results. Section 4.5 summarizes the chemical-specific distribution in the sediments at the Site. Sections 4.6 through 4.8 summarize data collected on porewater, clam tissue, and contaminant mobility test results, respectively. Section 4.9 presents the distribution of the risk-driver contaminants and defines the boundaries for the purposes of evaluating remedial alternatives in the FS.

This section builds upon and uses the conclusions of various interim RI/FS deliverables, including the *ERA*, *HHRA*, and the *Nature and Extent Summary Memorandum*, that were completed prior to this report. Conclusions from the risk assessments (e.g., identification of COCs and risk-driver COCs) were used in the evaluation of the nature and extent of sediment contamination.

4.1 DATA GAPS

The *RI/FS Work Plan* identified several data gaps for the Lockheed West Site that would require sampling and analysis to allow for the completion of the RI/FS. These data gaps and the sections in this RI/FS in which they are addressed included the following:

- Spatial resolution of the contaminants in the Site sediments as described in Sections 4.5 through 4.9;
- Depth of sediment contamination and volume as described in Section 4.9 and the FS;
- Physical characterization of the Site and adjacent areas as described in Section 2.0 and Section 4.3;
- Assessment of habitat distribution as summarized in Section 4.3;
- *HHRA* and *ERA* (refer to Section 7.0 for results summary);
- Sediment contaminant mobility as described in Sections 4.8 and 6.0;
- Sediment stability as addressed in Sections 4.0 and 6.0 and Appendix H; and
- Potential for sediment recontamination (refer to Section 5.0 for a results summary).

The RI sampling and analysis was completed according to the Sampling and Analysis Plan (Appendix C in the *RI/FS Work Plan*) to collect the necessary data to address the data gaps noted above and complete the RI/FS and allow for the selection of remedial alternatives for the Site. The *ERA* and *HHRA* are included in this report as Appendices B and C, respectively.

4.2 FIELD PROGRAM AND METHODS SUMMARY

This section presents the scope of the field activities and methods used. The physical characterization includes bathymetric and shoreline surveys that were conducted in the summer of 2006 and also a topographic survey that was completed in April 2007. Sediment sampling characterization activities were conducted during January and April 2007. In addition, a clam reconnaissance survey of the intertidal and subtidal areas of the Site was conducted in spring of 2008. Further details of the field program can be found in the *RI Data Report*. In general, the procedures and methods used to collect these data were as described in the Sampling and Analysis Plan and QAPP in the *RI/FS Work Plan*. A data quality evaluation is presented in Section 4.2.6 of this report.

4.2.1 Physical Characterization Studies

The bathymetric survey of the open-water area, shipways, and under-pier areas was performed to provide current elevations throughout the Site. The high-resolution multibeam bathymetry data were collected on May 20, 2006. Horizontal positioning is based on North American Datum (NAD) 1983 and vertical positioning was based on the Port of Seattle MLLW datum for Elliott Bay. The bathymetric survey results were presented in the *RI/FS Work Plan*.

The shoreline conditions survey documented the current physical conditions such as existing habitat and structures along the shoreline at the Lockheed West Site. The survey was performed August 9, 2006, during a daytime low tide and is also documented in the *RI Data Report*.

The topographic survey was conducted in April 2007 to document the current upland elevations to tie in the bathymetric survey. The survey area extended from the top of the shoreline bank to the edge of the water. The results of the topographic survey were merged with the bathymetric survey data and included in the *RI Data Report*.

4.2.2 Shoreline Survey

A team of Tetra Tech scientists and engineers conducted a site visit on August 9, 2006, to survey and document the current physical conditions along the shoreline to address the physical characterization and habitat data gaps identified in the *RI/FS Work P lan*. The survey was performed during a daytime low tide (-2.6 feet MLLW) to maximize the area available for the survey. The survey area is depicted in Figure 4-1.

Field activities at the Site included the following:

- Documenting the weather and tidal conditions during the survey;
- Systematically photographing the shoreline areas with overlapping photos;
- Recording the condition of shoreline, including the nature and extent of shore protection and debris;
- Recording substrate types and sizes;
- Documenting the relative slope angles and slope conditions;
- Recording types, conditions, locations, and extent of shoreline and nearshore structures, including pilings and bulkheads;

- Documenting presence/absence of biota;
- Documenting presence, size, material of construction, location, and condition of outfalls; and
- Documenting the presence, location, and extent of seeps along the shoreline.

4.2.3 Sediment Characterization Sampling

This section describes the RI surface and subsurface sediment characterization program. Sample locations for the 2007 RI are shown on Figure 4-2.

Surface Sampling. Surface sediment sampling included subtidal, porewater, and background range-finding surface samples collected in January 2007, and intertidal surface samples collected in April 2007.

- Subtidal surface sediment samples were collected using a standard van Veen grab deployed from a work vessel. These samples are representative of the upper 10 centimeters of sediment. In total, 42 subtidal surface sediment samples were collected and analyzed. Additional sediment samples were collected at all the surface grab locations and archived for potential PCB congener analysis and additional material was collected at seven of the sample locations for the analysis of porewater for the contaminants of interest (COIs).
- Background range-finding surface sediment samples were collected using a standard van Veen grab from a work vessel. In total, seven surface samples were collected. Proposed cleanup actions at the Site required characterization of background sediment quality conditions. The background range-finding process was intended to identify a representative range of concentrations for Lockheed West Site COPCs throughout Elliott Bay through sampling and chemical analysis of surface sediment samples collected from within the bay.
- Intertidal bank surface sediment samples were collected using bowls and spoons at low tide to allow field personnel to assess the slope and substrate for optimal sampling locations. Nine surface sediment samples were collected from the upper 10 centimeters of sediment for analysis.

Subsurface Sampling. Subsurface (core) sampling was performed at the Site using a vibracore system deployed from a vessel. Forty-five cores were collected at 35 locations. The cores ranged from 5 to 20 feet in length. Initially, 104 subsurface sediment samples were analyzed and

309 samples archived. Based on a review of the initial results from the first 104 samples, a second round of chemical analysis was conducted on 29 additional archived subsurface samples.

Contaminant Mobility Sample Collection. Two sediment composite samples representative of the contaminated sediment mass were created from the cores to support sediment contaminant mobility testing. Each composite was volume weighted (equal volume from unit length) from all cores based on chemical analyses and sediment stratigraphy as necessary to create a representative composite. Multiple cores were necessary at each location to collect adequate volumes for the planned analyses. The methods used for the contaminant mobility testing are noted in Section 4.2.5.3 and the results are summarized in Section 4.8 and Appendix A.

Surface Water Sample Collection. Surface water samples were collected from a representative location at the northeast corner of the Site from May 17 to 18, 2007, using a peristaltic pump and weighted Teflon-lined tubing drawn from 1 meter below the surface. These surface water samples were collected to serve as supply water for the column settling and elutriate tests.

The surface water samples were collected and analyses performed as part of the contaminant mobility testing and were not intended for site surface water characterization. The results are reported in the *RI Data Report*.

4.2.4 Clam Reconnaissance Survey

Clam samples were collected from one intertidal and three subtidal areas of the Site in April and May 2008. The clams collected from each area were composited into four samples, one for each area of collection, for submittal to the laboratory for chemical analysis. Composite sediment samples were also collected from each of the four areas. The results of the clam reconnaissance survey were reported in the *RI Data Report*. The results of the clam reconnaissance survey were used to confirm the appropriateness of the tissue biota-sediment accumulation factors (BSAFs) adopted from the LDW and used in the *HHRA*.

4.2.5 Laboratory Analysis

This section includes a summary of laboratory methods used for analysis of surface samples, subsurface samples, range-finding background samples, intertidal samples, and contaminant mobility tests.

4.2.5.1 Sediment Chemistry Methods

Sediment samples were analyzed for COIs by the methods listed in Table 4-1. The required detection limits were consistent with risk-based low-level detection limits of the LDW RI/FS project.

4.2.5.2 Geotechnical Test Methods

A suite of physical tests were conducted to evaluate dredging and capping methods, dredge material transport and placement, dredge material behavior in the disposal site, potential short-term impacts at the dredge and disposal sites, and capacity of existing sediments to provide foundation support for capping material.

The tests listed in Table 4-2 were completed for selected samples collected in the cores.

4.2.5.3 Contaminant Mobility Methods

Subsurface (core) sample increments representative of material that may be dredged were archived by freezing at Columbia Analytical Services, Inc., in Kelso, Washington. Selected samples were identified and blended into two composite sediment samples. The tests and methods used for the composite samples are listed below:

- Column Settling Test (CST; EPA and USACE, 1998)
- Dredge Elutriate Test (DRET; DiGiano et al., 1995)

The list of core-sample increments used to create the composite samples analyzed for contaminant mobility was provided in the *RI Data Report*.

The composite sediment samples were analyzed for the COIs listed in Table 4-1. The Site water used for the CST and DRET, and the elutriate samples were analyzed for the COIs as listed in Table 4-3.

4.2.6 Data Quality Evaluation

This section discusses the data quality evaluation including validation, data qualifiers, data reduction from multiple results, and calculation of analyte totals.

A total of 12 data packages (as referenced in the *RI Data Report*), corresponding to individual sample delivery groups, were generated by Columbia Analytical Services, Inc. The data packages were validated by Laboratory Data Consultants, Inc. (LDC), an independent data validation firm located in Carlsbad, California. The validation is summarized by LDC in a total of six data validation reports. Based on review of the data associated with sediment, intertidal, contaminant mobility, and the rinsate blank samples, overall data quality objectives specified in the QAPP (Tetra Tech, 2008a) were met. The data validation reports can be found in the *RI Data Report*.

4.2.6.1 Validation Levels and Criteria

Two levels of validation were performed for this project. Level 3 validation was performed on approximately 80 percent of the data. It consisted of an evaluation of the following items, as summarized in the data packages: holding times, calibrations, method blanks, field blanks, surrogate spikes, matrix spikes/matrix spike duplicates, laboratory control samples, and some method-specific requirements. Level 4 validation was performed on approximately 20 percent of the data. Level 4 validation, a more comprehensive effort, included an evaluation of those items included in a Level 3 validation, plus a review of the raw data to confirm that compounds were properly identified and data were correctly calculated and transcribed.

Data validation was performed using the guidance as described in *National Functional Guidelines for Inorganic Data Review* (EPA, 2004b) and *National Functional Guidelines for Organic Data Review* (EPA, 1999b). Data were validated in accordance with criteria specified in the EPA validation guidance, analytical methods, and QAPP. Validated data were qualified in cases when the criteria were not met or as deemed appropriate, based on the professional judgment of the validator.

4.2.6.2 Qualified Data

The majority of analytical data were within control limits with 99.8 percent of the results found to be usable for project purposes. Data qualifiers were applied when control limits were not met. Overall, project objectives were met and the laboratory analyses are considered usable for the intended purpose, with the exception of results that were rejected (R).

Qualified data were summarized in the *RI Data Report*. The majority of the quality control (QC) issues are related to the following: calibration outliers, blank contaminants, laboratory control sample outliers, matrix duplicate outliers, and differences between results obtained on two gas chromatograph columns. Some of the reported results may represent approximate concentrations due to these issues and are qualified as estimated (J/UJ). Some results are qualified as not detected (U) by the validator due to the likelihood of false positive results from trace contamination detected in analytical blank samples. Some results (less than 0.5 percent of the reported results) were rejected (R) due to recovery of less than 10 percent in the laboratory control sample analysis.

Control limit exceedances are typically encountered for data sets of this size and nature. The number of exceedances for this project was within the expected range, and associated data were appropriately addressed as indicated above.

4.2.6.3 Data Reduction for Multiple Results

There were several samples for which the laboratory reported multiple results for a target analyte such as where two EPA analytical methods (8081A and 8270C) were used to meet a detection limit, or where a sample was re-analyzed due to QC sample results not within acceptance criteria. In these cases, the laboratory reported both the original analysis and re-analysis. After LDC applied data qualifiers, Tetra Tech selected the result that was more appropriate and assigned one valid result per target analyte per sample. The following are guiding principles that were applied when selecting the single result that would be used when multiple results were reported:

1. When multiple results indicated the analyte was not detected, the lowest reporting limit for an undetected analyte was selected.
2. When one result was rejected (R) during data validation, the remaining result was selected.
3. When one result indicated a detection and the other result was not detected, the detected value was selected.
4. When multiple results indicated a detection, the highest value for a detected analyte was selected (except as noted below).

5. For sample TT42-SS, multiple results for mercury were reported. The result with the higher detected value was associated with QC samples that were not within acceptance criteria. Additionally, the result with the higher detected value appears to be an anomaly when compared to mercury results in the re-analysis, QC duplicates, and for other Site samples. Therefore, the value from the re-analysis for mercury was selected for this sample.

4.2.6.4 Calculating Total Concentrations

Concentrations of total PCBs, total dichlorodiphenyltrichloroethane (DDT), total heavy-weight PAH (HPAH), total light-weight PAH (LPAH), total benzofluoranthenes, total PAH, and total chlordanes were calculated using the procedures specified in the Washington State SMS (WAC 173-204).

Total PCBs were calculated using only detected values for nine Aroclor mixtures. For individual samples in which none of the Aroclor mixtures were detected, total PCBs were given a value equal to the highest reporting limit of the nine Aroclors and assigned a "U" qualifier indicating the lack of detected concentrations.

Total LPAHs represent the sum of detected concentrations for naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene. Total HPAHs are the sum of detected concentrations for fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3,-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. Total benzofluoranthenes represent the sum of the b (i.e., benzo(b)fluoranthene), j, and k isomers. Because the j isomer is not normally reported, this sum was calculated with only the b and k isomers. For samples in which all individual compounds within any of the three groups described above are undetected, the single highest reporting limit for that sample represents the sum.

Total carcinogenic PAHs (cPAHs) represent the sum of benzo(a)pyrene equivalents for the cPAHs (benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, and benzo[g,h,i]perylene). The individual PAH concentration is multiplied by the potency equivalent factor listed below and these equivalent concentrations are summed. If an individual PAH was non-detect, the reporting limit was used in the calculation.

Benzo(a)pyrene Equivalent Factors

- Benzo(a)anthracene 0.1
- Benzo(a)pyrene 1.0
- Benzo(b)fluoranthene 0.1
- Benzo(k)fluoranthene 0.1
- Chrysene 0.01
- Dibenzo(a,h)anthracene 0.4
- Indeno(1,2,3-cd)pyrene 0.1

Total DDTs were calculated using only detected values for the six DDT isomers: 2,4'-DDD, 4,4'-DDD, 2,4'-DDE, 4,4'-DDE, 4,4'-DDT, and 4,4'-DDT. For individual samples in which none of the isomers are detected, total DDTs are given a value equal to the highest reporting limit of the six isomers and assigned a "U" qualifier, indicating the lack of detected concentrations.

Total chlordane was calculated using only detected values for the following compounds: alpha-chlordane, gamma-chlordane, oxychlordane, cisnonachlor, and trans-nonachlor. For individual samples in which none of these compounds is detected, total chlordane was given a value equal to the highest reporting limit of the five compounds listed above and assigned a "U" qualifier, indicating the lack of detected concentrations.

4.2.7 Recent and Historical Data Used in RI Evaluation

In addition to the RI data collected between 2006 and 2008, additional data from other investigations have been selectively used in the RI. The recent and historical data included in the evaluation and the purpose for which they are used are listed in Table 4-4. Historical Site sampling locations are shown on Figure 4-3.

The supplemental data used in the RI were selected to help support the nature and extent and source control evaluations. All of the included data were assessed and validated as part of these historical data collection programs. The surface sediment samples collected in 2009 (Ecology, 2009a) and 2003 (Hart Crowser, 2003) are included because they represent recently collected

surface samples from the Site area. The subsurface core samples collected prior to 1998 have been deemed usable and included because subsurface core results are unlikely to have been impacted by changes in Site conditions, and the RI sampling program was more extensive and revisited many of the historical subsurface sample locations. The RI data set described and summarized in this report is the primary data set for all Site evaluations and conclusions. The supplemental data are included and used as a secondary supporting data set.

The recent collections of surface sediment data from Puget Sound (EPA, 2009a) and Elliott Bay (Ecology, 2009a) have provided data sets that have been used to help define the limits of the Site for the evaluation of remedial alternatives in the FS. These more recent data sets have been used in the RI data evaluation and FS alternatives evaluation in place of the range-finding data described in Section 4.2.2. The Puget Sound sediment data set includes 70 surface sediment samples collected by the Dredged Material Management Program (DMMP) agencies throughout Puget Sound in 2007 and is referred to as the "Bold Study." Surface sediment samples were collected by Ecology in 2007 from three regions of Elliott Bay defined as the "Harbor," "Urban," and "Basin" based on the sampling location proximity to industrial and shoreline areas of the bay.

4.3 PHYSICAL CHARACTERIZATION STUDY RESULTS SUMMARY

The observations from the shoreline survey, bathymetric survey, and topographic survey were presented in the *RI Data Report* and are summarized in this section.

4.3.1 Shoreline Survey Results

The weather conditions were partly cloudy with periods of sun and light showers during the August 9, 2006, Site visit.

Slopes along the shoreline ranged from very shallow to vertical. Substrates observed in the shoreline area included medium sand, shell hash, small- to medium-size cobbles, medium to large riprap, concrete keel blocks, cut-off and broken-off wood pilings, and debris, including trash, wire rope, concrete and ductile iron piping, and portions of deteriorated wooden bulkheads. Biota observed included crabs, barnacles, algae, kelp, starfish, mussels, and clams.

Seeps were observed in the area between the Florida Street Outfall and the Terminal 5 Pier, as well as between the concrete pier just north of the Florida Street Outfall and the northeast corner of the shoreline. Several pipes, in addition to the Florida Street Outfall, were observed along the eastern and northern shorelines. No significant discharge was noted from any of the pipes during this inspection or a later shoreline inspection performed in April 2009 as part of the source control evaluation (Tetra Tech, 2009b). The majority of the shoreline north of the Florida Street outfall is bulkheaded. Bulkhead types include single wooden, double wooden, steel sheetpile, and concrete bulkheads (very small area). In general, the wooden bulkheads were observed to be in poor to very poor condition, and the concrete and steel sheetpile bulkheads were observed to be in good condition.

Representative photos showing shoreline condition and features are included in Appendix A.1 of the *RI Data Report* along with video documentation of the condition of the shoreline and shoreline habitat on DVD (Appendix A.2 of the *RI Data Report*). The observations made during the shoreline surveys are presented in Figures 4-4 through Figure 4-8.

The shoreline habitat is typical of the industrial shoreline in much of the Duwamish Waterway with armoring and sheet pile bulkheads, along with broken pilings, deteriorating wooden bulkheads, and debris. The shoreline surveys documented the presence of a single, small intertidal beach area located along the West Waterway between the Terminal 5 pier and the South Florida Street Outfall. Current shoreline conditions within the remainder of the Site boundary indicate a highly modified and impacted industrial shoreline with little to no natural intertidal habitat.

4.3.2 Bathymetry/Topographic Survey and Subtidal Observations

A bathymetry survey and topographic survey were completed to fill the physical characterization and habitat data gaps identified in the *RI/FS Work Plan*. The high-resolution multibeam bathymetric survey of the Site and the upland topographic survey were combined to provide a complete elevation surface for the Site (Figure 4-9). The bathymetry survey shows that within the subtidal zone there are numerous debris piles in the area of the former dry docks and multiple pilings on the seafloor throughout. The industrial nature and development history, including

dredging activities, is evident at the Site and the type of habitat at the Site is limited by these conditions.

4.4 SEDIMENT PHYSICAL CHARACTERISTICS

This section summarizes the physical characteristics of the sediments at the Lockheed West Site.

4.4.1 Sediment Grain Size

Table 4-5 summarizes the grain size results for the surface and subsurface samples and Appendix A contains the complete grain size results. Field observations of the surface sediment samples indicated that the sediment consists primarily of dark-gray, silty sand. The results of the grain size analyses show that the surface sediments were generally sand with silt and, to a lesser extent, clay and gravel. The range for percent sand in the subtidal surface sediment samples is 11.2 to 98.5 percent with all but three samples being at least 50 percent sand. Surface samples collected from the intertidal areas had a higher sand content than the subtidal surface sediments, ranging between 54.3 and 99.9 percent sand.

The grain size analysis indicated that the sediment core samples were mostly sand with smaller percentages of silt and clay present. The subsurface sediment cores generally consisted of dark-gray sand or silty sand with a silt layer present at the mudline. One exception to this was location TT35-CS, which consisted of clay throughout the core. Several of the cores collected from the areas of the former dry docks (samples TT06, TT07, TT-08, TT09, TT15, and TT17) contained material that resembled sand-blast grit (refer to Figure 4-2).

4.4.2 Sediment Geotechnical Results

Thirty-eight subsurface samples were collected for specific gravity analysis during the RI sampling and 4 samples were also analyzed for Atterberg limits. The specific gravity of the subsurface cores ranged from 1.33 grams per cubic centimeter (g/cc) to 2.08 g/cc with an average of 1.68 g/cc. The Atterberg limits for the four samples were found to be non-plastic. Appendix A includes the sample geotechnical results. These results will be used in the FS and during remedial design for evaluation of remediation and disposal alternatives.

4.5 CHEMICAL-SPECIFIC NATURE AND EXTENT INFORMATION

This section presents the interpretation of the nature and extent of contaminants in the surface sediment, sediment cores, porewater, and clam tissue. A full summary of the chemical data for the surface and subsurface samples collected is also presented in the following sections. The data were initially summarized and presented in *RI Data Report*. Chemical data have been presented on maps, figures, and tables to depict the distribution of all the compounds analyzed.

This evaluation was focused on the horizontal and vertical extent of sediment contamination by risk-driver contaminants as identified in the risk assessments (Section 7.0). These risk-driver contaminants were arsenic, copper, lead, mercury, PCBs, TBT, dioxins/furans, and cPAHs. The cPAH concentration is the total toxicity equivalent quotient (TEQ) for the PAHs identified as carcinogenic.

The Washington State SMS (WAC 173-204) have been identified as applicable or relevant and appropriate requirements (ARARs) for evaluating sediment contamination. They have accordingly been adopted for screening-level comparisons within this RI because they are the generally accepted benchmarks although they do not represent the final cleanup standards. These promulgated sediment regulations represent standards for the protection of benthic invertebrates. The benthic invertebrate SMS define two levels of chemical and biological standards. The more stringent level, the SQS, corresponds to a sediment quality that has no acute or chronic adverse effects on benthic marine organisms. The less stringent level, the cleanup screening level (CSL), is the level above which minor adverse effects are likely to occur in benthic marine organisms. According to the SMS, sediment cleanup standards for benthic invertebrates are established on a site-specific basis (WAC 173-204-570). The site-specific standard must be between the SQS, which is the cleanup objective, and the CSL, also known as the minimum cleanup level (MCUL).

For the summary of detected compounds, the data are presented in terms of dry-weight results. For the comparison to SMS levels (SQS and CSL) where the criterion is organic carbon normalized, the sediment data were converted to milligrams per kilogram organic carbon (mg/kg-OC) if the percent of organic carbon is greater than 0.5 percent. Where the organic carbon sample content is less than 0.5 percent, the results were compared to the lowest apparent effects threshold (LAET) or the second-lowest apparent effects threshold (2LAET) for the SQS

and CSL levels, respectively. These screening levels represent non-promulgated dry-weight values that are accepted by Ecology for evaluation of marine sediments when organic carbon content is low. The numerical SQS and CSL values along with the LAET and 2LAET values are presented in Table 4-6.

4.5.1 Surface Sediment

This section presents the distribution and concentrations of chemicals detected in the surface sediments at the Lockheed West Site.

Table 4-7 summarizes the surface sediment data collected. This summary includes the number of samples with detections for each compound, the concentration ranges detected, mean of the detected results, and the range of the detection limits for non-detect results. Table 4-8 shows number of samples with exceedances of the SQS criteria and the CSL criteria. For comparison, sample concentrations are compared to the SQS and CSL levels to come up with a relative exceedance factor. The exceedance factor is an indication of how high the reported sample concentrations are relative to the numerical sediment standards, although it is not necessarily a representation of risk. Figures 4-10 and 4-11 show the locations and relative exceedance factor of the SQS and the CSL criteria, respectively, by groups of compounds (metals, LPAH, HPAH, PCBs, miscellaneous SVOCs, and TBT) for surface samples collected in 2003. Figures 4-12 and 4-13 show the relative SQS and CSL exceedance factors, respectively, for the RI surface samples collected in 2007.

4.5.1.1 Metals

Metals were detected in the surface sediments at frequencies ranging from 57.5 percent to 100 percent of the samples. Arsenic, chromium, copper, lead, mercury, and zinc were detected at concentrations above the SQS level at frequencies ranging from 4.1 to 44 percent of the samples. Mercury was the metal detected most frequently above the SQS (44 percent) and the CSL (33 percent). Metals were found at concentrations above the SQS in the intertidal areas, the former dry dock areas, the former shipway, and in the area to the east between the former lease boundary and the West Waterway OU boundary (Figures 4-10 and 4-12).

4.5.1.2 Tributyltin

TBT was detected in all of the surface sediment samples collected during the RI field events. The concentrations ranged from 0.81 microgram per kilogram dry weight (µg/kg-dw) to 4,500 µg/kg-dw. Because TBT does not have an SMS criterion, the West Waterway Confirmational Number (WWCN) 1,335 µg/kg-dw (76 mg/kg-OC) was used for comparison. The WWCN was derived to evaluate TBT contamination based on the concentrations that are characteristic in the adjacent West Waterway (EPA 2003a,b). This level is similar to the 10th percentile (i.e., 1.33 mg/kg-dw) for the sublethal effects data for TBT (EPA 1999a). Five surface sediment samples were found to have exceedances of the WWCN for TBT. The surface sediment samples with concentrations above the WWCN were detected in the area of the former dry docks (Figure 4-12).

4.5.1.3 Polycyclic Aromatic Hydrocarbons

At least one PAH compound was detected in each surface sediment sample collected during the RI sampling. Seventy-two of 73 samples had detectable levels of LPAHs, and all had detectable levels of HPAHs and cPAHs. Two samples had concentrations for LPAHs above the SQS and 15 surface sediment samples had concentrations of HPAHs above the SQS (refer to Figures 4-10 and 4-12). For the individual PAH compounds, benzo(g,h,i)perylene was most frequently detected above the SQS (28.8 percent). The highest concentrations of LPAHs were detected at locations near the PSR Marine Sediment Unit boundary on the west side of the Site (TT25-SS) and in the area of the former dry docks (TT14-SS and TT17-SS). For the HPAHs and cPAHs, the highest concentrations were detected at locations in the area of the former dry docks (TT14-SS, TT17-SS, and TT-31SS) and in the area of the former shipway (TT26-SS).

4.5.1.4 Semivolatile Organic Compounds

Several miscellaneous SVOCs were detected in the surface sediment samples collected at the Site. The classes of compounds detected included phthalates and phenols. Bis(2-ethylhexyl)phthalate (100 percent) was the most frequently detected miscellaneous SVOC in the surface sediment samples collected during the RI sampling. Dibenzofuran, di-n-butylphthalate, phenol, and butyl benzyl phthalate were detected in more than one-half of the surface sediment samples collected, while pentachlorophenol and 4-methylphenol were detected in slightly less than one-half of the surface sediment samples collected. Other detected SVOC compounds were

reported in less than 10 percent of the surface sediment samples collected. Bis(2-ethylhexyl)phthalate was detected in 8 of 73 samples at a concentration above the SQS. Other compounds with concentrations detected above the SQS included dibenzofuran, hexachlorobenzene, and pentachlorophenol. Surface sediment samples with SVOC concentrations above the SQS are located in and around the area of the former dry docks (refer to Figures 4-10 and 4-12).

4.5.1.5 Polychlorinated Biphenyls

Total PCBs were detected in all surface sediment samples collected during the RI. The concentrations detected in the surface sediments ranged from 4.2 µg/kg-dw to 3,000 µg/kg-dw. Of the surface samples collected, 59 of the 73 had concentrations above the SQS (12 mg/kg-OC) and 11 had concentrations above the CSL (65 mg/kg-OC). The highest concentrations of total PCBs in the surface sediments were detected at location HC-03-18 at the northern end of one of the former dry dock areas. Samples with the highest concentrations of total PCBs were found in and around the areas of the former dry docks and the areas of the former piers (refer to Figures 4-10 and 4-12).

4.5.1.6 Pesticides

At least one pesticide compound was detected in every surface sediment sample collected during the RI. The compounds DDT and chlordane were the most frequently detected in the surface sediment samples. The highest concentrations for the pesticides detected were found at locations TT17-SS and TT40-SS. The pesticide results were evaluated in the *HHRA* and *ERA* and total chlordanes and total DDTs are identified as non-risk-driver COCs (see Section 7.0).

4.5.1.7 Total Organic Carbon

The total organic carbon (TOC) content in the surface sediment samples collected from the subtidal area ranged from 0.1 to 5.33 percent with an average TOC content of 1.5 percent. Samples collected from the intertidal area ranged from 0.1 to 0.49 percent with an average of 0.3 percent.

4.5.2 Sediment Cores

Table 4-9 summarizes data for the samples analyzed from the cores collected during the RI sampling. Figures 4-14 and 4-15 show the exceedances of the SQS and CSL levels, respectively, for the historic cores collected at the Site. Figures 4-16 and 4-17 show the exceedances of the SQS and CSL levels, respectively, for the cores collected during the RI phase in 2007. Table 4-10 summarizes the number of historic and 2007 sediment core samples that exceed the SQS and CSL levels.

4.5.2.1 Metals

Individual metals were detected in 73.2 to 100 percent of the subsurface sediment samples collected during the RI sampling events. Arsenic, chromium, copper, lead, mercury, and zinc were detected above the SQS in between 4.4 and 33 percent of the subsurface sediment samples. Mercury was most frequently detected above the SQS (33 percent) in the subsurface sediments. Mercury was also the most frequently detected metal above the CSL (27 percent) in the subsurface sediments. The highest concentrations of metals were detected at locations TT08-CS (arsenic, copper, and zinc), TT15-CS (chromium and mercury), and M1 (lead). These locations are all in the area of the former dry docks (refer to Figures 4-14 through 4-17). Elevated concentrations for metals were further detected at locations TT06-CS, TT07-CS, and TT09-CS, also located in the area of the former dry docks. At a number of sampling locations (TT04-CS, TT25-CS, TT24-CS TT39-CS, and TT35-CS), mercury was the only metal detected above the SQS in the subsurface samples collected (refer to Figures 4-14 through 4-17).

4.5.2.2 Tributyltin

During the RI investigation, TBT was detected in 84.1 percent of the subsurface samples collected at the Site. The concentrations detected ranged from 0.21 µg/kg-dw to 9,100 µg/kg-dw (Table 4-9). The highest detected concentration for TBT was from sample station TT09-CS. Six sediment core locations had TBT detected above the WWCN (76 mg/kg-OC). Figure 4-16 shows that samples with exceedances above the WWCN (TT06-CS, TT07-CS, TT08-CS, TT09-CS, TT15-CS, and TT17-CS) are found in the former drydock areas with the one other location (TT91-CS) being located along the shoreline just to the west of the former dry docks area.

4.5.2.3 Polycyclic Aromatic Hydrocarbons

Individual PAHs were detected in 74.7 to 96.8 percent of the subsurface samples collected and analyzed during the RI investigation. The concentration of LPAHs detected ranged from 1.8 µg/kg-dw to 107,420 µg/kg-dw. For HPAHs, detected concentrations ranged from 1.8 µg/kg-dw to 163,900 µg/kg-dw. The highest concentrations for LPAHs, HPAHs, and cPAHs were detected at locations SB-1, TT07-CS, and TT-08CS, all located in the area of the former dry docks (refer to Figures 4-15 and 4-17). Higher concentrations for PAHs were also detected at location TT-25CS located in the area of the former shipway and near the edge of the PSR Marine Sediment Unit. All of the PAH compounds were detected above the SQS and CSL in at least three samples with acenaphthene the most frequently detected PAH above the SQS (56 samples) and CSL (36 samples).

4.5.2.4 Semivolatile Organic Compounds

The most commonly detected miscellaneous SVOC compounds in the surbsurface sediments were bis(2-ethylhexyl)phthalate, di-n-butylphthalate, aniline, dibenzofuran, 4-methlyphenol, and phenol. Other miscellaneous SVOC compounds, if detected, were found in less than 10 percent of the subsurface samples collected during the RI sampling. Only dibenzofuran, bis(2-ethylhexyl)phthalate, di-n-octylphthalate, and pentachlorophenol were detected in any subsurface samples above the SQS (refer to Figures 4-14 and 4-16).

4.5.2.5 Polychlorinated Biphenyls

Total PCBs were detected in 114 of the 160 subsurface sediment samples collected during the RI sampling. Concentrations ranged from 4.1 µg/kg-dw to 9,620 µg/kg-dw (Table 4-9). The highest concentration was detected at location TT15-CS in the area of the former dry docks. Of the subsurface samples collected, 74 had concentrations above the SQS and 36 had concentrations exceeding the CSL (refer to Figures 4-15 and 4-17). Samples with exceedances of the SQS are found in the areas of the former dry docks near the former piers and at two locations (TT34-CS and TT39-CS) along the top of the slope north of the shipyard (refer to Figures 4-14 and 4-16).

4.5.2.6 Pesticides

At least one individual pesticide compound was detected in the subsurface sediment samples with oxychlordane being detected in 2 of the 160 samples collected and p,p’-DDT being the most

frequently detected pesticide (101 of 160 samples). In addition to p,p'-DDT, the most commonly detected pesticides were p,p'-dichlorodiphenyldichloroethane (DDD), endrin aldehyde, o,p'-DDD, o,p'-DDT, and cis-nonachlor. Other pesticides if detected were found in less than 50 percent of the subsurface samples collected. The highest concentrations for detected pesticides were found at locations TT04-CS, TT07-CS, TT08-CS, TT14-CS, TT15-CS, TT17-CS, and TT37-CS (refer to Figures 4-15 and 4-17 for sample locations). There are no SMS standards for pesticide compounds and the subsurface sediment results were not used in the risk assessments because the exposure pathways for subsurface sediments are not complete.

4.5.2.7 Total Organic Carbon

The TOC content in the samples collected from the subsurface during the RI sampling at the Site ranged from 0.05 to 4.59 percent with an average TOC content of 1.1 percent. To compare sample results for the sediment samples to the CSL and SQS criteria, concentrations of organic compounds (as specified in the SMS) were normalized where the percent organic carbon in the sample was greater than 0.5 percent. If the percent organic carbon was less than or equal to 0.5 percent, the dry-weight results were compared to the LAET or 2LAET criteria. The TOC results are included in the summary of analytical results in Appendix A.

4.6 POREWATER

Table 4-11 summarizes the results for the seven porewater samples collected during the RI sampling. Figure 4-2 shows the porewater locations, and Appendix A provides the results of the porewater sample analysis.

The porewater samples were collected to provide data for potential use in the risk assessments and site-specific data for fate and transport processes at the sediment water interface. The modeling for the risk assessments, however, was performed using a BSAF method, which essentially eliminates the need for porewater data for risk assessment. Therefore, the porewater data collected as part of the RI were generally not utilized (except for porewater TBT results) in the risk assessments. Site-specific porewater TBT results were compared to toxicity reference values in the *ERA* to screen for potential ecological effects.

The porewater data and co-located sediment results were also used to calculate site-specific sediment-water partitioning values. These results are further discussed in Section 6.0. In addition, the porewater results will be used during remedial design to evaluate capping effectiveness, if capping is a component of the remedial action.

4.7 CLAM TISSUE

To support the assumptions used in the *HHRA* and *ERA*, clam tissue samples were collected as part of the RI sampling. BSAFs were developed from Lockheed West Site data to determine whether those proposed for tissue modeling in the *HHRA* and *ERA* were sufficiently conservative. These data are presented in this section and summarized in the *RI Data Report*.

Table 4-12 summarizes the detected parameters in clam tissue. The four composite clam tissue samples were analyzed for total PCBs and metals and all four had detectable concentrations of PCBs and all of the metals analyzed. Concentrations of PCBs ranged from 17 to 66 µg/kg-wet weight (ww). Only three of the four composite clam tissue samples had sufficient tissue mass available for PAH, pesticide, TBT, and dioxins/furans analysis. These analyses are also presented in Table 4-12.

In conjunction with the clam tissue sample collection, composite surface sediment samples were collected from the areas from which the clams were collected. The composite surface sediment samples were analyzed for metals, PCBs, pesticides, PAHs, butyltins along with dioxins and furans. In the subtidal areas, the dioxin TEQ concentrations ranged from 2.41 to 13.8 nanongrams per kilogram (ng/kg) dw and in the intertidal area the detected concentration was 0.687 ng/kg-dw. Table 4-13 summarizes the results for the four sediment samples and Appendix A provides a complete summary of the results.

A comparison of the BSAFs derived from Site data (i.e., sediment and tissue sample results) was completed; it verified that the BSAFs from the LDW were suitable for use in the uptake modeling and were sufficiently conservative and appropriate for use in the risk assessments for the Lockheed West Site. The uncertainties in the BSAFs and impacts on calculated risks are discussed in detail in the *HHRA* and are summarized in Section 7. The modeled clam tissue concentrations were found to be greater than the measured clam tissue data for almost all of the compounds evaluated. The measured tissue concentrations were higher for chromium, TBT, and

total PCBs than the modeled concentrations. The use of the higher measured concentration had only a minimal change in the risk estimates.

4.8 CONTAMINANT MOBILITY RESULTS

Two composite sediment samples were collected for DRET and CST. The DRET results for the two sediment samples collected have been used to evaluate the potential for short-term contaminant releases at the point of dredging. The CST results have been used to evaluate the settling behavior of the sediments that may be dredged at the Site. The CST results will be used during the design phase to assess impacts from dredging and to evaluate short-term effects. Copper was detected in the unfiltered elutriate samples above the marine acute criteria. Several pesticides were also detected in the elutriate samples or had reporting limits above the marine acute criteria level. The analytical results of the composite sediment samples and Site water used for the tests, the elutriate samples, and the CST settling results are included in Appendix A.

4.9 SITE CHARACTERISTICS

The horizontal and vertical extent of contamination was determined based on an evaluation of the surface sediment and sediment core data collected for the risk-driver compounds compared to various reference data sets described below. Based on these evaluations, the Site has been adequately defined for purposes of alternatives evaluation that will follow in the FS.

4.9.1 Reference Data Summaries

The *ERA* and *HHRA* identified a total of eight compounds (arsenic, copper, lead, mercury, total PCBs, cPAHs, TBT, and dioxins/furans) as risk-drivers for the Lockheed West Site sediments. The concentrations for the risk-driver contaminants were compared to the applicable risk-based threshold concentrations (RBTCs) or natural background concentrations as represented by the the 95 percent upper confidence level (95 UCL) “Bold Study” values (EPA, 2009a); the 95 UCL of the Elliott Bay Harbor, Urban, and Basin data (Ecology, 2009a); and SQS criteria. These screening criteria and the basis of their derivation were described in the *Nature and E xtent Summary Memorandum* and are summarized below.

The SQS, RBTCs, and recent regional sediment sampling data sets (“Bold Study” and Ecology [2009a] Elliott Bay Deep Basin, Urban, and Harbor areas) have been compiled to provide a set of

reference data against which the Lockheed West Site sediments can be compared. The source of these data sets and their use are summarized in Table 4-14.

For the recent regional sediment sampling data sets, the 95 UCL was calculated for the risk-driver compounds to use for the comparisons. A summary of sediment reference data set values along with the site-specific RBTC and SQS criteria is included in Table 4-15. The data results used to determine the 95 UCL for the "Bold Study" and the Ecology (2009a) Elliott Bay Basin, Urban, and Harbor areas are included in Appendix A.

Data for dioxins and furans were not collected at the Site during the 2007 RI sampling and therefore their distribution is not shown in the nature and extent figures. However, they were identified as risk-driver contaminants in the *HHRA* based on their assumed likely presence in the Site sediment and seafood, as they are documented to be in the upstream Lower Duwamish Waterway and represent a COC at the nearby PSR Marine Sediment Unit. During the Clam Survey (see Section 4.7), the presence of dioxins/furans at the Site was confirmed. The current plans to remediate the Lockheed West Site will mitigate the potential risks to human health and environment associated with likely co-location of dioxins and furans with other organic contaminants (PCB, cPAHs) in the sediments. The risk-assessment approach and planned performance criteria for the remediation are intended to be generally consistent with those developed for the LDW.

The comparison process used to help define the extent of contamination incorporated the promulgated standards, site-specific RBTCs (as defined in Section 9.0), and various reference data sets indicative of contaminant concentrations in the surrounding area. The SQS and CSL represent promulgated Washington State sediment standards data that are intended to be protective of benthic invertebrate ecologic receptors. The RBTCs represent concentrations determined to be protective of the identified human and ecological receptors for the Lockheed West Site and represent a lower range of risk-based concentrations for comparing Site sediment data.

Some of the RBTCs (arsenic, cPAHs, and total PCBs) are below analytical detection capabilities and/or below the concentrations detected in the samples collected from Puget Sound as part of the "Bold Study" survey (EPA, 2009a) (Table 4-15). The "Bold Study" data set has been

identified by EPA as the representative natural background conditions for sediments in the Puget Sound region. The reported concentrations of cPAHs and total PCBs from the "Bold Study" are very low when compared to sites located in more developed areas, such as Elliott Bay (Table 4-15). These low values limit the utility of the "Bold Study" data set for defining site boundaries limited in urban areas as is evident in the Ecology (2009a) Elliott Bay study data sets (i.e., the Ecology study values are higher than the "Bold Study" values for these constituents).

The Elliott Bay Urban Water initiatives study identified three different areas of sediment in Elliott Bay (Basin, Urban, and Harbor) that are impacted to different extents by anthropogenic activities. The Harbor concentrations represent typical concentrations in sediments of the industrialized area including the Lower Duwamish Waterway, the East Waterway, and the West Waterway. The concentrations in the Urban and Basin areas represent typical concentrations in areas impacted by anthropogenic activities and are lower than those in the Harbor area but still above the "Bold Study" values.

These reference data sets represent the site-specific risk-based levels, ranges of sediment conditions from the surrounding area, and regulatory levels that are relevant to the Lockheed West study area. These data sets have been used to define the nature and extent of the contamination in the sediments at the Lockheed West study area. The nature and extent of contamination presented in this section will define the geographic extent of contamination to be addressed in the FS and be used in the determination of Site cleanup levels.

4.9.2 Three-Dimensional Sediment Contamination Visualization

To estimate the extent of site-related contamination, the collected sediment data and the bathymetric survey were used to create a three-dimensional (3-D) model of the sediment concentrations using a 3-D visualization software program (C-Tech MVS). Recent sediment data collected for the monitoring program at the PSR site (SAIC, 2008), post-remedy samples collected at Todd Shipyard (Floyd|Snider, 2007), and data from the 2007 Elliott Bay sampling event (Ecology, 2009a) were used to provide bounds on the model.

The 3-D model used a kriging approach to estimate the concentrations of contaminants in the sediment based on the data in the model data set. The software model default values for the kriging interpolation were used for estimating the sediment concentrations across the area. A

sensitivity analysis was completed by adjusting the model parameters for model reach and model anisotropy. The model reach defines how many data points from the model data set are used in estimating the value at locations between sample locations. Adjustments that lowered and increased the number of sample points used resulted in only small differences in the estimated extent of sediment contamination. Adjustments of the anisotropy, which varies the relative influence of sample points in the horizontal and vertical dimension on the data interpolation, also resulted in only small differences in the estimated extent of sediment contamination.

An evaluation of the 3-D model setup, uncertainty, and sensitivity is presented in Appendix D.

4.9.3 Horizontal Extent of Risk-Driver Sediment Contamination

Figures 4-18 to 4-24 present the output from the 3-D model for the risk-driver contaminants. The plan view of the figures shows the horizontal extent of the sediment concentrations exceeding associated screening value(s) for all surface and subsurface samples. Figures 4-18 through 4-23 each present five plots showing the Lockheed West Site sediment areas that exceed the SQS; the 95 UCL of the Elliott Bay Harbor, Urban, and Basin data; and the greater of the RBTC or the 95 UCL for the "Bold Study" data. Figure 4-24 includes two plots to illustrate TBT concentrations: one plot shows Lockheed West Site sediment areas that exceed the WWCN and the other plot shows the areas that exceed the RBTC. The WWCN was selected because there is not an SQS value for TBT, and it represents a screening value previously used at other nearby cleanup sites that can be used for general comparison purposes.

Figure 4-18 shows the comparison results for arsenic. The areas with sediment arsenic concentrations above the SQS are found in the former dry dock areas and in the intertidal sediments near the former shipway area. The former dry docks and shipway represent areas where shipyard activities were historically active. The presence of the higher concentrations of arsenic in these locations is expected and likely indicates that the majority of the contamination was deposited and remains proximal to where those activities took place. The broad extent of arsenic above the Elliott Bay Urban, Basin, and "Bold Study" values suggests that area concentrations (Table 4-15) generally exceed these criteria and, therefore, the comparison with these values is not a good indicator of Site-related contamination.

Figure 4-19 shows the distribution of copper in sediments above the SQS; the Elliott Bay Harbor, Urban, and Basin values; and the RBTC. For copper, the RBTC is higher than the "Bold Study" 95 UCL data set, so it was used in the figures for comparison. Higher concentrations of copper generally occur in the same locations as elevated arsenic and TBT (see Figures 4-18 and 4-24) and are found in the former dry dock areas and intertidal sediments in the area of the former shipway. These areas of greater concentration are most likely where the majority of the shipyard activities occurred and indicate that the majority of the contamination was deposited near where these historical activities were conducted. A single surface sample location (TT-SS34) at the northeast corner of the study area also had a reported concentration above the SQS. The figure also shows the extent of the sediment copper concentrations above the Elliott Bay Urban, Basin, and RBTC levels. Similar to arsenic, comparison with these criteria seems to indicate more area-wide copper impacts and is not a good indicator of Site-related contamination. However, copper concentrations decrease near the Outer Harbor Line, which suggests that the Outer Harbor Line serves as a reasonable site boundary for this compound.

Figure 4-20 shows the distribution of lead in sediments above the SQS; the Elliott Bay Harbor, Urban, and Basin values; and "Bold Study" 95 UCL. For lead, the area with sediment concentrations above the SQS is limited and located within the former dry docks and intertidal sediments. The area with concentrations of lead above the Elliott Bay Basin 95 UCL and the "Bold Study" 95 UCL is similar to those areas of arsenic and copper and is not a good indicator of Site-related contamination.

Mercury sediment concentrations above the SQS and the Elliott Bay Harbor, Urban, and Basin values are found in the former dry dock areas and also to the west of these areas along one of the former piers (Figure 4-21). The RBTC for mercury is equal to the SQS. One location in the northeast corner of the study area (TT34-SS) and a few locations on the west side of the study area and to the south also had concentrations above the SQS/RBTC. The distribution of mercury above SQS/RBTC screening levels suggests that it is likely related to historical shipyard activities in and around the former dry docks and piers. The occurrence of mercury at other locations in the West Waterway suggests potential impacts from other sources, which also appear indicated by the areas shown with estimated concentrations above both the Elliott Bay Basin and the "Bold Study" 95 UCLs.

Figure 4-22 shows the comparisons of total PCBs with the SQS; the Elliott Bay Harbor, Urban, and Basin values; and "Bold Study" 95 UCL. The concentrations for total PCBs in the sediments that exceed the SQS are found in the former dry dock areas and in the areas along several of the former piers (Figure 4-22). In addition, three surface locations towards the northeast corner of the study area also had concentrations detected above the SQS. The areas with sediment concentration above the Elliott Bay Urban 95 UCL are similar to the area above the SQS. Data from the study area and from other recent sampling in the surrounding area show that the Elliott Bay-wide sediment concentrations exceed the 95 UCL from the "Bold Study" data for total PCBs. The extent of sediment concentrations above the "Bold Study" 95 UCL for total PCBs shows that, based on the available data, it is not possible to differentiate shipyard-related contamination from the non-shipyard-impacted sediments at the level of the "Bold Study" data. The "Bold Study" reference data do not provide a means to define site-specific contamination for total PCBs in the sediments.

Figure 4-23 shows the comparisons of cPAH concentrations with the SQS; the Elliott Bay Harbor, Urban, and Basin values; and "Bold Study" 95 UCL. There is no available SQS value for cPAHs. The extent of such contamination in the study area has been evaluated by using the SQS value for benzo(a)pyrene, which was determined to represent approximately 75 percent of the cPAHs for the sediment samples collected. The use of the benzo(a)pyrene SQS dry weight equivalent represents a conservative comparison for the cPAH TEQ because if there was an available SQS for cPAHs, it would be higher than the benzo(a)pyrene value. The locations with elevated cPAH concentrations are found in the former dry dock areas and on the western side of the study area in the vicinity of the former shipway. There are also elevated cPAHs in areas adjacent to the PSR Marine Sediment Unit. The areas with sediment concentrations above the Elliott Bay Harbor and Urban 95 UCLs are similar to the SQS area. As with total PCBs, the 95 UCL from the "Bold Study" data does not allow for differentiation of shipyard-impacted sediments from non-shipyard-impacted sediments for cPAHs at the edges of the Lockheed West study area. The "Bold Study" reference data for cPAHs do not provide a means to define the extent of Site-related contamination.

Figure 4-24 shows the comparisons of TBT in sediments with the WWCN and RBTC. The West Waterway confirmation value is used for comparison purposes because no SQS value is

available. The WWCN has been used as a threshold screening level at other sites in the area and is the most comparable level to SQS available. The former dry dock areas have TBT concentrations above the WWCN with a couple of additional locations located near the former piers. The comparison to the RBTC suggests that Site-related shipyard activity impacts a few areas in addition to the former dry docks but that impacts from other shipyards also occur in the area.

The horizontal extent of shipyard-related sediment contamination in the study area can generally be defined based on exceedances of the SQS level. The area over which total PCBs and cPAHs exceed the "Bold Study" 95 UCL values (i.e., 2 µg/kg-dw and 8 µg/kg-dw) is unbounded (i.e., extends throughout Elliott Bay) and the entire extent cannot be attributed to former Site activities. There are some locations, such as around sampling location TT-SS34, where concentrations of copper, mercury, and PCBs are elevated relative to the SQS and additional data collection may be required depending on the final cleanup levels and the selected remedy. This will be determined in the remedy design phase as data needs are identified.

4.9.4 Vertical Extent of Contamination for the Risk-Driver Compounds

To illustrate the vertical extent of contamination, a series of transects, using data from the subsurface core locations, was established through the Lockheed West study area (shown on Figure 4-25). The cores along each transect for each risk-driver contaminant show the vertical extent of the sediment contamination in the study area. Transect A-A′ shows sediment cores collected along the eastern side of the study area from approximately 300 feet north of the Terminal 5 pier to just north of the former lease boundary. Transect B-B′ shows cores collected from just west of the West Waterway OU boundary to the former shipway area on the western side of the study area just north of the uplands (Terminal 5). Transect C-C′ includes cores between the West Waterway OU boundary to the PSR Marine Sediment Unit boundary approximately 300 feet to 500 feet north of the uplands. Transect D-D′ shows the sediment cores collected along the northern boundary of the former lease area. Selected cores are projected onto the transects from their actual locations. Some core logs have been offset on the transects for presentation purposes.

Figures 4-26 through 4-32 show the core intervals relative to the SQS for the risk-driver contaminants. Figures 4-33 through 4-38 show the concentrations for arsenic, copper, lead, mercury, total PCBs, and cPAHs compared against the 95 UCL for the Elliott Bay Urban data. The locations of the deepest areas with concentrations above the SQS are in the former dry dock areas. For the majority of the sediment cores collected, the deepest sample interval analyzed was found to have concentrations for the risk-driver compounds, with the exception of PCBs, less than the SQS level. At those locations, such as the historic cores around TT09-CS where the deepest interval had a concentration above the SQS, data from cores nearby indicate that the likely vertical extent of contamination is not substantially deeper. Similarly for location TT08-CS, the defined depths at TT06-CS and TT09-CS indicate that contamination above the SQS is likely not to be substantially deeper.

Cores along Transect A-A′ show that sediment concentrations for arsenic, copper, lead, and TBT that are above the SQS generally occur in the area of the former Dry Dock 1. Mercury was found to have concentrations above the SQS in the 0- to 1-foot interval at locations outside the Dry Dock 1 area (TT-11, TT-34, and TT-35 and also at multiple intervals at location TT-04). Concentrations of PCBs were also found above the SQS at locations outside the Dry Dock 1 area (TT-04, PC-2, and TT-34).

Transects B-B′ and C-C′ show that concentrations above the SQS were found in the former dry dock areas, between the former piers, and around the former shipway area on the western side of the Site. Transect D-D′ shows that for most of the risk-drivers the concentrations detected in the sediments were below the SQS, except for mercury and PCBs. In addition, the data from all of the transects generally indicate that the extent of contamination can be vertically bounded throughout the study areas based on comparison to SQS and, to a lesser extent, the Elliott Bay Urban 95 UCL. All but six locations for PCBs; three locations for copper, mercury, and arsenic; and one location for lead have the deepest interval with concentrations below SQS. Compared to the Elliott Bay Urban 95 UCL, the number of cores increases most for arsenic (14) and copper (9) due to the larger differences between the SQS level and the Elliott Bay Urban level.

Figures 4-39 and 4-40 show the sediment concentrations in the cores along the same transects but the sediment concentrations are compared to the “Bold Study” 95 UCL for arsenic (7 mg/kg) and

total PCBs (2 µg/kg-dw), respectively. For arsenic, the core data indicate that at many locations the concentration in the deepest interval is higher than the "Bold Study" 95 UCL level. The other risk-driver metals show a similar pattern to arsenic. For total PCBs and cPAHs, the "Bold Study" 95 UCL levels are very low; for total PCBs (shown in Figure 4-40), the level is below the sample reporting limit for the data collected. Therefore, the vertical extent of the contamination throughout the study area cannot be established using the "Bold Study" values for comparison.

There are a small number of areas, including a portion of former Dry Dock 1 (TT08), one location along the shore (TT04), and a location off the former shipway (TT25), where the deepest sample collected from the Site in 2007 was found to have contaminant concentrations above the SQS thresholds. These areas may need additional data collected to determine the depth of contamination as part of the remedial design. Any additional data collection will be outlined in a future sampling and analysis plan to be submitted for review and approval during the remedial design phase.

4.9.5 Extent of Contamination in the Study Area

Sediment data were collected during the RI field effort to define the nature and extent of the Site-related sediment contamination in the Lockheed West study area. The study area has a physical boundary defined by the shoreline along much of the southern end of the study area. The western and eastern sides of the study area have as administrative boundaries the PSR Marine Sediment Unit and the West Waterway OU, respectively. To evaluate the extent of the sediment contamination for the northern boundary, the concentrations of the risk-driver compounds have been compared to the SQS, RBTC, and the 95 UCL of the "Bold Study" data set. Figures 4-41 through 4-43 summarize the exceedance footprints of the risk-driver compounds as compared to the SQS and RBTC or 95 UCL "Bold Study" data.

Figure 4-41 shows an overlay of the extent of sediment contamination above the SQS or WWCN for arsenic, copper, lead, mercury, TBT, and cPAHs. The locations where sediment concentrations for multiple potential shipyard-related contaminants were detected above the SQS levels are generally found in the areas where the majority of the shipyard activities occurred. These include the areas of the former dry docks, the shipway, and piers. The extent of sediment with any exceedance of a SQS level for these compounds is generally contained within the area previously

leased or owned by Lockheed Martin. The SQS levels for these risk-driver contaminants provide a reasonable basis for defining the areas where the shipyard-related activities have impacted the sediments.

Figure 4-42 shows the extent of the sediment with concentrations for total PCBs above the SQS (dry-weight equivalent). The areas with sediment concentrations above the SQS are generally contained within the Lockheed West study area and include the former dry docks and the piers. However, the extent of sediment with PCB concentrations above the SQS is substantially broader than for the other risk-driver contaminants shown in Figure 4-41. This broader extent is mostly due to elevated concentrations in surficial sediments. As described in the *Source C ontrol Evaluation R eport*, this indicates that concentrations associated with recently deposited sediments from ongoing sources are potentially contributing to the contamination at the Site and that there are areas within the Lockheed West Site not impacted by historical Site-related activities that contain elevated concentrations of PCBs.

Figure 4-43 shows an overlay of the extent of sediment with concentrations above the RBTC or the 95 UCL from the "Bold Study" data for arsenic, copper, lead, and TBT. The extent of sediment contamination above the RBTC or the 95 UCL from the "Bold Study" for arsenic, copper, lead, and TBT does not differ sufficiently from surrounding area background concentrations to be useful in distinguishing Site-specific contamination. However, the exceedance area for the metals (arsenic, copper, lead, and mercury) generally does not extend to the north beyond the top of the shelf along the Outer Harbor Line. The exceedance footprint for these contaminants does not extend down the slope to the deep basin area of Elliott Bay and shows a definitive northern boundary for use in determining the remedy area boundaries (refer to Figure 4-43). For PCBs and cPAHs, where the Elliott Bay-wide sediment concentrations are significantly above the RBTC or the 95 UCL from the "Bold Study" (Figures 4-22 and 4-23), the comparison to these criteria cannot bound the Site in any meaningful way and are not included. Note that since the RBTC for mercury is the SQS level, the extent of mercury sediment contamination is already included in Figure 4-41. The boundary defined by the extent of sediment concentrations for arsenic, copper, lead, and TBT above the RBTC or the 95 UCL from the "Bold Study" provides a basis for the evaluation of alternatives in the FS.

4.9.5.1 Study Area Boundary

As discussed above, Figure 4-41 shows the areas where, based on the results for risk-driver (which are also indicators of shipyard-related contaminants), the impacts due to shipyard-related activities are present. Figure 4-42 shows the areal extent of the PCB sediment contamination above the SQS, which is potentially impacted by recently deposited surficial sediments. Figure 4-43 is not useful for definitively delineating shipyard-related impacts from surrounding area concentrations, but does provide a basis to support the definition of a northern boundary for Site-related metals contamination along the top of the slope near the Outer Harbor Line.

Figure 4-44 shows the horizontal study area boundary based on the extent of sediment contamination above the SQS for cPAHs (Figure 4-41) and PCBs (Figure 4-42) and above the RBTCs or "Bold Study" 95 UCL levels for risk-driver metals. The Lockheed West study area northern boundary is based on the contiguous definable extent of risk-driver sediment concentrations above the RBTC or "Bold Study" 95 UCL (see Figure 4-43). These boundaries will be useful in comparing remediation alternatives as part of the FS and can be defined by the following:

- The top of the slope, also where the Outer Harbor Line is shown to the north and extending east along the top of bank contour to the West Waterway OU boundary;
- The PSR Marine Sediment Unit boundary to the west;
- The West Waterway OU to the east; and
- The southern boundary, defined by both the uplands area of Terminal 5 and the in-water area between the Terminal 5 uplands and the West Waterway OU where sediment concentrations are above the SQS.

The vertical extent of the Site-related sediment contamination in the study area can be defined using SQS levels (see Figures 4-26 through 4-32). At a limited number of locations, the depth of contamination above the SQS is not completely defined (see Section 4.9.5 discussion).

4.10 SUMMARY

Data were collected at the Site to address data gaps as identified in the *RI/FS Work Plan*. Major findings for the physical characteristics of the Site and the nature and extent of contamination are discussed in this section.

A bathymetric survey and shoreline surveys were conducted to provide a physical characterization of the Site and adjacent areas and to evaluate Site sediment stability. The evaluation of the bathymetric survey indicates that based on the presence of distinct historic features in the Site area that the sediments are characterized by a low net depositonal rate and are relatively stable. This conclusion was also supported by wave analysis.

The shoreline surveys show that current conditions are typical of a highly modified and industrial shoreline. The survey documented the presence of several pipes and the SW Florida Street Outfall along the eastern and northern shorelines. The surveys also documented that the substrate along the shore included medium sand, shell hash, small- to medium- size cobbles, medium to large riprap, concrete keel blocks, cut-off and broken-off wood pilings, and debris, including trash, wire rope, concrete and ductile iron piping, and portions of deteriorated wooden bulkheads. Bulkheads along the shore include single wooden, double wooden, steel sheetpile, and concrete bulkheads; the wooden bulkheads were observed to be in poor to very poor condition and the concrete and steel sheetpile bulkheads to be in good condition. The shoreline surveys documented the presence of a single, small intertidal beach area located along the West Waterway between the Terminal 5 pier and the SW Florida Street Outfall with very limited undisturbed intertidal habitat.

Subtidal sediments consisted primarily of sand and silt. Samples of surface and subsurface sediment were collected during the RI field sampling events to define the nature and extent of contamination at the former Lockheed West Site. The results of the sampling and analysis conducted showed that metals, including arsenic, cadmium, copper, lead, mercury, and zinc along with organics, including PCBs, LPAHs, HPAHs, pentachlorophenol, and bis-(2-ethylhexyl)phthalate, were detected above the SQS in the surface and subsurface sediments. Areas with sediment concentrations above the SQS included the former drydocks and along the former piers. In addition, the intertidal area of the former shipway had concentrations above the SQS for metals including arsenic, copper, lead, and zinc.

For the purposes of establishing a remedy boundary to evaluate as part of the FS, the horizontal extent of potential Site-related sediment contamination in the Lockheed West study area is discussed in Section 4.9 above and shown in Figure 4-44.

Table 4-1.
Parameters of Interest for the Site Characterization

Parameters	Analysis	Sediment Target Detection Limit[1/]
Grain Size	PSEP, 1986/ASTM-D422	0.1 retained
Total Organic Carbon	SW-846 9060/EPA 415.1	500 mg/kg
Tributyltins compounds (TBT)	Krone et al., 1989	1-5 µg/kg
Metals	SW-846 6010B	0.03 – 1 mg/kg
Mercury	SW-846 7471A	0.003 µg/kg
PCB Aroclors[2/]	SW-846 8082	0.98 µg/kg
Pesticides	SW-846 8081A	0.024- 30 µg/kg
Semivolatiles	SW-846 8270D	0.006 – 0.1 mg/kg
PAHs	SW-846 8270-SIM	0.001 – 0.05 µg/kg
Archived		
PCB Congeners[3/]	SW-846 8082	0.35 – 0.95 ng/kg
Dioxin/Furnas[3/]	Method 1613	0.059 – 0.518 ng/kg

Notes:
Samples with high moisture contents or matrix interference may have detection limits higher than those listed.
EPA test methods are found in SW-846, Test Methods for the Evaluation of Solid Waste Physical/Chemical Methods.
1/ Detection limits are on wet-weight basis. Detection limits on dry-weight basis are dependent on total solids content.
2/ PCB Aroclors analyzed included 1016, 1221, 1232, 1242, 1248, 1254, and 1260. Detected Aroclors were summed to determine total PCBs.
3/ Sediment was archived for potential analysis of PCB congeners and dioxin/furans.
µg/kg = microgram/kilogram
mg/kg = milligram/kilogram
ng/kg = nanogram/kilogram
PAHs = polycyclic aromatic hydrocarbon
PCBs = polychlorinated biphenyl

Table 4-2.
Geotechnical Parameters and Methods

Grain Size	PSEP, 1986
Atterberg Limits	ASTM D 4318-95
Specific Gravity	ASTM D 854-92

Notes:
ASTM = American Society for Testing and Materials

Table 4-3.
Chemicals of Interest for the Elutriate Samples

Analyte	Units	Marine Acute Criteria[1/]	Reporting Limit
Arsenic	µg/L	69	6.9
Cadmium	µg/L	40	4.2
Chromium (VI)	µg/L	1100	110
Copper	µg/L	4.8	0.48
Lead	µg/L	210	21
Mercury	µg/L	1.8	0.18
Nickel	µg/L	74	7.4
Selenium	µg/L	290	29
Silver	µg/L	1.9	0.19
Zinc	µg/L	90	9
Pentachlorophenol	µg/L	13	1.3
4,4 DDT	µg/L	0.13	0.013
Aldrin	µg/L	1.3	0.13
Chlordane	µg/L	0.09	0.009
Dieldrin	µg/L	0.71	0.071
Endosulfan I (alpha-Endosulfan)	µg/L	0.034	0.0034
Endosulfan II (beta-Endosulfan)	µg/L	0.034	0.0034
Endrin	µg/L	0.037	0.0037
Heptachlor	µg/L	0.053	0.0053
Heptachlor Epoxide	µg/L	0.053	0.0053
Hexachlorocyclohexane (gamma BHC, Lindane)	µg/L	0.16	0.016
Toxaphene	µg/L	0.21	0.021
Total PCBs[2/]	µg/L	10	1
Total Suspended Solids	mg/L	NA	NA

Notes:
1/ Marine Acute - EPA Saltwater Criteria Maximum Concentration criteria value. This value is the acute limit for the priority pollutant in saltwater (EPA, 2002a). Arsenic through Toxaphene criteria are from the table: National Recommended Water Quality Criteria for Priority Toxic Pollutants.
2/ The Marine Acute Criterion for total PCBs is from Washington Administrative Code Chapter 173-201A.
NA = not applicable
µg/L = microgram per liter
mg/L = milligram per liter
PCB = polychlorinated biphenyl

Table 4-4.
Recent and Historical Site Data Used in the Remedial Investigation

Study	Sampling Year/Sampler	Samples Collected	Analysis Performed	Use in Remedial Investigation
Elliott Bay	2009, Ecology	2 surface sediment grab samples	Metals, PCBs, Pesticides, SVOCs, Conventionals*, Grain size	Used as part of the surface sediment data set to determine the nature and extent of contamination at the site
Lockheed Shipyard 2 Sediment Characterization	2003, Hart Crowser	19 surface sediment grab samples	Metals, PCBs, Pesticides, SVOCs, VOCs, Dioxins, Conventionals*, Grain Size,	Used with the 2007 RI data to delineate the nature and extent of surface sediment contamination at the site and to evaluate surface sediment concentration trend in the source control evaluation report
Enviros Lockheed Shipyard No. 2 Sediment Characterization and Geotechnical Study	1990	Sediment cores	Metals, PCBs, Pesticides, SVOCs, VOCs, Dioxins TBT, Conventionals*, Grain size	Used with RI sediment core data to evaluate the extent of subsurface contamination
Southwest Harbor Remedial Investigation Sediment Quality Investigation	1991	8 sediment cores	Metals, PCBs, SVOCs, VOCs, Conventionals*	Used with RI sediment core data to evaluate the extent of subsurface contamination
Southwest Harbor PSDDA-related Sediment Quality investigation	1992	2 sediment cores	Metals, PCBs, Pesticides, SVOCs, VOCs, Conventionals*	Used with RI sediment core data to evaluate the extent of subsurface contamination

Notes:
*Conventionals includes percent moisture, total organic carbon.
PCB = polychlorinated biphenyl
PSDDA = Puget Sound Dredge Disposal Analysis
RI = remedial investigation
SVOC = semivolatile organic compound
TBT = tributyltin
VOC = volatile organic compound

Table 4-5.
Summary of Surface and Subsurface Sediment Grain Size Distributions

Sediment Type	Grain Size Class	Range (Percent)		Mean
		Min	Max	
Subtidal Surface sediments (45 samples)	Gravels	0.08	72	5.7
	Sands	11.2	98.5	60.9
	Silts	3.4	49.2	24.7
	Clays	2.3	20.5	10.1
Intertidal sediments (9 samples)	Gravels	3	54	23
	Sands	54.3	99.9	81.5
	Silts	0.1	1.8	0.4
	Clays	0.4	1.1	0.8
Subtidal subsurface sediments (133 samples)	Gravels	0	41.3	3.4
	Sands	4.3	95.5	62.5
	Silts	0.9	72.2	28.3
	Clays	0.8	33.0	6.6

Table 4-6.
Summary of Sediment Standards and LAET / 2LAET Values (Page 1 of 2)

Parameter	SQS	CSL	LAET[1/]	2LAET[1/]
Metals (mg/kg)				
Arsenic	57	93	N/A	N/A
Cadmium	5.1	6.7	N/A	N/A
Chromium	260	270	N/A	N/A
Copper	390	390	N/A	N/A
Lead	450	530	N/A	N/A
Mercury	0.41	0.59	N/A	N/A
Silver	6.1	6.1	N/A	N/A
Zinc	410	960	N/A	N/A
Organics (mg/kg OC)				
1,2,4-Trichlorobenzene	0.81	1.8	31	51
1,2-Dichlorobenzene	2.3	2.3	35	50
1,4-Dichlorobenzene	3.1	9	110	120
2-Methylnaphthalene	38	64	670	1,400
Acenaphthene	16	57	670	1,400
Acenaphthylene	66	66	1,300	1,300
Anthracene	220	1200	960	4,400
Benzo(a)anthracene	110	270	1,300	1,600
Benzo(a)pyrene	99	210	1,600	3,000
Benzo(g,h,i)perylene	31	78	670	720
Benzofluoranthenes (total)	230	450	3,200	3,600
bis(2-ethylhexyl)phthalate	47	78	1,300	1,900
Butyl benzyl phthalate	4.9	64	63	900
Chrysene	110	460	1,400	2,800
Dibenzo(a,h)anthracene	12	33	230	540
Dibenzofuran	15	58	540	700
Diethylphthalate	61	110	200	1,200
Dimethyl phthalate	53	53	71	160
Di-n-butyl phthalate	220	1700	1,400	5,100
Di-n-octyl phthalate	58	4500	6,200	nv
Fluoranthene	160	1200	1,700	2,500
Fluorene	23	79	540	1,000
Hexachlorobenzene	0.38	2.3	22	70
Hexachlorobutadiene	3.9	6.2	11	120
Indeno(1,2,3-cd)pyrene	34	88	600	690
Naphthalene	99	170	2,100	2,400
N-Nitrosodiphenylamine	11	11	28	40
Phenanthrene	100	480	1,500	5,400
Pyrene	1000	1400	2,600	3,300
Total HPAH	960	5300	12,000	17,000
Total LPAH	370	780	5,200	13,000

Table 4-6.
Summary of Sediment Standards and LAET, 2LAET values (Page 2 of 2)

Parameter	SQS	CSL	LAET[1/]	2LAET[1/]
Tributyltin	76	N/A	1.335 [3/]	N/A
cPAHs	1.1[2/]	3.0[2/]	N/A	N/A
Total PCBs	12	65	130	1,000
2,4-Dimethylphenol	0.029	0.029	0.029	0.029
2-Methylphenol	0.063	0.063	0.063	0.063
4-Methylphenol	0.67	0.67	0.67	0.67
Benzoic acid	0.65	0.65	0.65	0.65
Benzyl alcohol	0.057	0.073	0.057	0.073
Pentachlorophenol	0.36	0.69	0.36	0.69
Phenol	0.42	1.2	0.42	1.2

Notes:
1/ All concentrations in milligrams per kilogram dry weight.
2/ SQS and CSL values are for benzo(a)pyrene.
3/ Value for tributyltin is the West Waterway Confirmational Number.
cPAH = carcinogenic polycyclic aromatic hydrocarbon
CSL = Cleanup Screening Level
HPAH = heavy-weight polycyclic aromatic hydrocarbon
2LAET = second lowest apparent effects threshold
LAET = lowest apparent effects threshold
mg/Kg OC = milligram per kilogram organic carbon
N/A = not applicable
PCB = polychlorinated biphenyl
SQS = Sediment Quality Standard
OC = Organic Carbon

Table 4-7.
Subtidal and Intertidal Surface Sediment Summary of Detected Parameters (Page 1 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum Detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
Metals							
Antimony	54	100.0	0.43	194	TT11-SS	19	-
Arsenic	73	100.0	4.56	330	TT-IT-06	42	-
Cadmium	73	100.0	0.04	1.05	HC-03-03	0.35	-
Chromium	73	100.0	14.4	504	TT18-SS	74	-
Cobalt	54	100.0	3.18	38.6	TT-IT-06	9.3	-
Copper	73	100.0	28.2	1900	TT15-SS	266	-
Lead	73	100.0	15.9	1420	TT-IT-02	145	0.0019 - 0.058
Mercury	73	100.0	0.021	2.94	TT17-SS	0.47	-
Molybdenum	54	100.0	0.36	23.8	TT-IT-06	3.8	-
Nickel	54	100.0	7.29	151	TT-IT-08	28	-
Selenium	35	64.8	0.2	1.2	TT11-SS, TT14-SS, TT15-SS	0.72	0.4 - 0.5
Silver	73	100.0	0.071	1.31	HC-03-06	0.32	-
Thallium	54	100.0	0.033	0.314	TT-IT-06	0.11	-
Vanadium	54	100.0	22	95.6	TT18-SS	50	-
Zinc	73	100.0	47.5	1430	TT11-SS	312	-
TBT							
Tributyltin	73	100.0	0.00081	4.5	TT30-SS	0.62	-
PAHs							
1-Methylnaphthalene	8	14.8	0.0033	0.16	TT25-SS	0.038	0.0026 - 0.36
2-Methylnaphthalene	64	87.7	0.0016	0.19	TT25-SS	0.035	0.0014 - 0.044
Acenaphthene	70	95.9	0.0028	0.45	TT25-SS	0.084	0.0012 - 0.0014
Acenaphthylene	72	98.6	0.003	0.65	TT14-SS	0.084	0.0018 - 0.0018
Anthracene	72	98.6	0.0039	2.5	TT26-SS	0.30	0.0018 - 0.0018
Benzo(a)anthracene	73	100.0	0.0026	2.7	TT26-SS	0.57	-
Benzo(a)pyrene	73	100.0	0.0026	2.3	HC-03-18	0.58	-

Table 4-7.
Subtidal and Intertidal Surface Sediment Summary of Detected Parameters (Page 2 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum Detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
PAHs (Continued)							
Benzo(b)fluoranthene	54	100.0	0.005	3.4	TT14-SS	0.85	-
Benzo(g,h,i)perylene	73	100.0	0.0043	1.3	TT17-SS	0.31	-
Benzo(k)fluoranthene	53	98.1	0.0073	1.5	TT31-SS	0.34	0.0032 - 0.0032
Benzofluoranthenes (total)	73	100.0	0.005	4.6	HC-03-18, TT14-SS	1.3	-
Chrysene	73	100.0	0.0031	5.8	TT14-SS	0.90	-
Dibenzo(a,h)anthracene	71	97.3	0.0036	0.34	TT17-SS	0.095	0.0028 - 0.003
Fluoranthene	73	100.0	0.0045	33	TT14-SS	1.6	-
Fluorene	70	95.9	0.0028	0.47	TT25-SS	0.11	0.002 - 0.0023
Indeno(1,2,3-cd)pyrene	73	100.0	0.0029	1.4	TT17-SS	0.35	-
Naphthalene	68	93.2	0.002	0.61	TT25-SS	0.081	0.0015 - 0.047
Phenanthrene	72	98.6	0.0045	3.2	TT17-SS	0.61	0.0017 - 0.0017
Pyrene	73	100.0	0.0038	23	TT14-SS	1.4	-
Total cPAH	54	100.0	0.003681	2.9	TT17-SS	0.77	-
Total HPAH	73	100.0	0.0288	70.7	TT14-SS	7.1	-
Total LPAH	72	98.6	0.0129	4.8	TT17-SS	1.3	0.0022 - 0.0022
PCBs							
PCBs (total)	73	100.0	0.0042	3	HC-03-18	0.42	-
Pesticides							
Aldrin	2	3.7	0.003	0.0035	TT04-SS	0.0033	0.00018 - 0.0059
alpha-BHC	0	0.0	-	-	-	-	0.0003 - 0.011
alpha-Chlordane	0	0.0	-	-	-	-	0.00027 - 0.009
delta-BHC	8	14.8	0.00017	0.0036	TT31-SS	0.0020	0.000064 - 0.0022
Dieldrin	7	13.0	0.00051	0.021	TT17-SS	0.008	0.00034 - 0.012
Endosulfan I	6	11.1	0.00031	0.016	TT40-SS	0.0044	0.0002 - 0.0066

Table 4-7.
Subtidal and Intertidal Surface Sediment Summary of Detected Parameters (Page 3 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum Detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
Endosulfan II	4	7.4	0.00043	0.008	TT09-SS	0.0031	0.00022 - 0.0074
Endosulfan sulfate	6	11.1	0.0017	0.024	TT22-SS	0.0057	0.000091 - 0.0031
Endrin	4	7.4	0.00029	0.0005	TT-IT-02, TT-IT-04	0.00043	0.00023 - 0.0078
Endrin aldehyde	24	44.4	0.00012	0.017	TT40-SS	0.0049	0.000062 - 0.0021
gamma-Chlordane	36	66.7	0.00013	0.046	TT17-SS	0.0084	0.000075 - 0.0023
Heptachlor	0	0.0	-	-	-	-	0.000092 - 0.0032
Heptachlor epoxide	8	14.8	0.0005	0.01	TT10-SS, TT17-SS, TT40-SS	0.0058	0.00015 - 0.005
Methoxychlor	21	38.9	0.0005	0.015	TT25-SS, TT30-SS	0.0053	0.00012 - 0.0039
Mirex	12	22.2	0.00012	0.01	TT10-SS, TT31-SS, TT40-SS	0.0040	0.00012 - 0.0039
Nonachlor (cis)	15	27.8	0.0003	0.015	TT08-SS	0.0064	0.000096 - 0.0031
Nonachlor (trans)	20	37.0	0.00016	0.01	TT10-SS, TT11-SS, TT14-SS, TT17-SS, TT31-SS, TT40-SS, TT42-SS	0.0054	0.00011 - 0.0035
o,p-DDD	42	77.8	0.00025	0.11	TT17-SS	0.018	0.00027 - 0.0076
o,p-DDE	7	13.0	0.00082	0.027	TT40-SS	0.011	0.00027 - 0.009
o,p-DDT	45	83.3	0.00036	0.09	TT40-SS	0.017	0.00017 - 0.0046
Oxychlordane	0	0.0	-	-	-	-	0.00043 - 0.015
p,p-DDD	17	31.5	0.00023	0.014	TT17-SS	0.0057	0.00014 - 0.0047
p,p-DDE	3	5.6	0.0018	0.01	TT17-SS	0.0056	0.00012 - 0.0039
p,p-DDT	54	100.0	0.00028	0.12	TT40-SS	0.020	-
Total chlordane	31	57.4	0.00014	0.046	TT17-SS	0.010	0.00044 - 0.014
Total DDT	52	96.3	0.00028	0.294	TT17-SS	0.044	0.0065 - 0.0067

Table 4-7.
Subtidal and Intertidal Surface Sediment Summary of Detected Parameters (Page 4 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum Detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
Toxaphene	25	46.3	0.015	0.97	TT40-SS	0.27	0.011 - 0.35
Other SVOCs							
1,2,4-Trichlorobenzene	0	0.0	-	-	-	-	0.0018 - 0.054
1,2-Dichlorobenzene	1	1.4	0.0027	0.0027	TT15-SS	0.0027	0.0015 - 0.054
1,3-Dichlorobenzene	0	0.0	-	-	-	-	0.0019 - 0.06
1,4-Dichlorobenzene	5	6.8	0.0035	0.0099	TT15-SS	0.0050	0.0022 - 0.069
2,4,5-Trichlorophenol	0	0.0	-	-	-	-	0.0035 - 0.11
2,4,6-Trichlorophenol	0	0.0	-	-	-	-	0.0021 - 0.065
2,4-Dichlorophenol	0	0.0	-	-	-	-	0.0021 - 0.065
2,4-Dimethylphenol	0	0.0	-	-	-	-	0.0064 - 0.2
2,4-Dinitrophenol	0	0.0	-	-	-	-	0.042 - 1.3
2,4-Dinitrotoluene	0	0.0	-	-	-	-	0.0033 - 0.11
2,6-Dinitrotoluene	0	0.0	-	-	-	-	0.0033 - 0.11
2-Chloronaphthalene	0	0.0	-	-	-	-	0.0042 - 0.13
2-Chlorophenol	0	0.0	-	-	-	-	0.002 - 0.061
2-Methylphenol	1	1.4	0.016	0.016	TT15-SS	0.016	0.004 - 0.13
2-Nitroaniline	0	0.0	-	-	-	-	0.0032 - 0.097
2-Nitrophenol	0	0.0	-	-	-	-	0.003 - 0.094
3,3-Dichlorobenzidine	0	0.0	-	-	-	-	0.0043 - 0.14
3-Nitroaniline	0	0.0	-	-	-	-	0.003 - 0.094
4,6-Dinitro-o-cresol	0	0.0	-	-	-	-	0.002 - 0.061
4-Bromophenyl phenyl ether	0	0.0	-	-	-	-	0.0017 - 0.051
4-Chloro-3-methylphenol	0	0.0	-	-	-	-	0.0025 - 0.076
4-Chloroaniline	0	0.0	-	-	-	-	0.0025 - 0.076
4-Chlorophenyl phenyl ether	0	0.0	-	-	-	-	0.0023 - 0.072
4-Methylphenol	32	43.8	0.0041	0.39	HC-03-15	0.038	0.0034 - 0.11

Table 4-7.
Subtidal and Intertidal Surface Sediment Summary of Detected Parameters (Page 5 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum Detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
4-Nitroaniline	2	3.7	0.026	0.055	TT40-SS	0.041	0.004 - 0.13
4-Nitrophenol	0	0.0	-	-	-	-	0.035 - 1.1
Aniline	1	1.9	0.013	0.013	TT06-SS	0.013	0.0018 - 0.054
Benzoic acid	0	0.0	-	-	-	-	0.12 - 3.5
Benzyl alcohol	6	8.2	0.0063	0.014	TT15-SS	0.0082	0.0043 - 0.14
beta-BHC	0	0.0	-	-	-	-	0.00035 - 0.012
bis(2-chloroethoxy)methane	0	0.0	-	-	-	-	0.0015 - 0.047
bis(2-chloroethyl)ether	0	0.0	-	-	-	-	0.0028 - 0.087
bis(2-chloroisopropyl)ether	0	0.0	-	-	-	-	0.0014 - 0.044
bis(2-ethylhexyl)phthalate	73	100.0	0.0032	0.89	HC-03-18	0.22	-
Butyl benzyl phthalate	48	65.8	0.0033	0.096	TT17-SS	0.026	0.0018 - 0.054
Dibenzofuran	69	94.5	0.0022	0.4	TT25-SS	0.059	0.0015 - 0.047
Diethylphthalate	1	1.4	0.012	0.012	TT12-SS	0.012	0.0041 - 0.13
Dimethyl phthalate	3	4.1	0.0043	0.011	TT06-SS	0.007	0.0021 - 0.065
Di-n-butyl phthalate	60	82.2	0.0035	0.069	TT17-SS	0.020	0.0097 - 0.094
Di-n-octyl phthalate	2	2.7	0.029	2.6	TT-IT-08	1.3	0.0014 - 0.06
Hexachlorobenzene	4	5.5	0.0002	0.0029	TT18-SS	0.0017	0.000091 - 0.022
Hexachlorobutadiene	0	0.0	-	-	-	-	0.00057 - 0.06
Hexachlorocyclopentadiene	0	0.0	-	-	-	-	0.018 - 0.54
Hexachloroethane	0	0.0	-	-	-	-	0.0026 - 0.079
Nitrobenzene	0	0.0	-	-	-	-	0.0023 - 0.072
N-Nitrosodimethylamine	1	1.9	0.038	0.038	TT15-SS	0.038	0.0071 - 0.22
N-Nitroso-di-n-propylamine	0	0.0	-	-	-	-	0.0037 - 0.12
N-Nitrosodiphenylamine	0	0.0	-	-	-	-	0.0026 - 0.079
Pentachlorophenol	31	42.5	0.016	0.57	TT30-SS	0.18	-
Phenol	57	78.1	0.0054	0.18	HC-03-08	0.045	0.0022 - 0.18

Table 4-7.

Subtidal and Intertidal Surface Sediment Summary of Detected Parameters (Page 6 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum Detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)

Notes:
Detected results include estimated concentrations below the sample reporting limits.
mg/kg-dw = milligram per kilogram dry weight
HPAH = heavy-weight polycyclic aromatic hydrocarbon
LPAH = light-weight polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SVOC = semivolatile organic compound

Table 4-8.
Comparison of Surface Sample Results to the Sediment Management Standards (Page 1 of 3)

Parameter	SQS/CSL	Unit Basis	LAET/2LAET (µg/kg-dw)	Number Samples Exceeding SQS/LAET	Percent Exceeding SQS/LAET	Number Samples Exceeding CSL/2LAET	Percent Exceeding CSL/2LAET
PAHs							
Acenaphthylene	16/57	mg/kg-OC	500/730	6	8.2	2	2.7
Benzo(a)anthracene	110/270	mg/kg-OC	1,300/1,600	9	12.3	1	1.4
Benzo(a)pyrene	99/210	mg/kg-OC	1,600/3,000	9	12.3	1	1.4
Benzofluoranthenes (total)	230/450	mg/kg-OC	3,200/3,600	5	6.8	1	1.4
Benzo(g,h,i)perylene	31/78	mg/kg-OC	6,760/720	21	28.8	2	2.7
Chrysene	110/460	mg/kg-OC	1,400/2,800	15	20.5	1	1.4
Dibenzo(a,h)anthracene	12/33	mg/kg-OC	230/540	14	19.2	2	2.7
Fluoranthene	160/1200	mg/kg-OC	1,700/2,500	19	26	0	0
Indeno(1,2,3-cd)pyrene	34/88	mg/kg-OC	600/690	15	20.5	2	2.7
Phenanthrene	100/480	mg/kg-OC	1,500/5,400	11	15.1	0	0
Pyrene	1000/1400	mg/kg-OC	2,600/3,300	0	0	0	0
Acenaphthene	16/57	mg/kg-OC	500/730	6	8.2	2	2.7
Anthracene	220/1200	mg/kg-OC	960/440	0	0	0	0
Fluorene	23/79	mg/kg-OC	1,700/2,500	5	6.8	0	0
Naphthalene	99/170	mg/kg-OC	2,100/2,400	1	1.4	0	0
2-Methylnaphthalene	38/68	mg/kg-OC	670/1,400	0	0	0	0
Total LPAH	370/780	mg/kg-OC	5,200/13,000	2	2.7	1	1.4
Total HPAH	960/5300	mg/kg-OC	12,000/17,000	15	20.5	0	0
Other SVOCs							
1,2-Dichlorobenzene	2.3/2.3	mg/kg-OC	35/50	0	0	0	0
1,4-Dichlorobenzene	3.1/9	mg/kg-OC	110/120	0	0	0	0
1.,2,4-Trichlorobenzene	0.81/1.8	mg/kg-OC	31/51	0	0	0	0
2-Methylphenol	63/63	µg/kg-dw	63/63	0	0	0	0
4-Methylphenol	670/670	µg/kg-dw	670/670	0	0	0	0
2,4-Dimethylphenol	29/29	µg/kg-dw	29/29	0	0	0	0

Table 4-8.
Comparison of Surface Sample Results to the Sediment Management Standards (Page 2 of 3)

Parameter	SQS/CSL	Unit Basis	LAET/2LAET (µg/kg-dw)	Number Samples Exceeding SQS/LAET	Percent Exceeding SQS/LAET	Number Samples Exceeding CSL/2LAET	Percent Exceeding CSL/2LAET
Benzyl alcohol	57/73	µg/kg-dw	57/73	0	0	0	0
Benzoic Acid	650/650	µg/kg-dw	650/650	0	0	0	0
Butyl benzyl phthalate	4.9/64	mg/kg-OC	63/900	0	0	0	0
Dibenzofuran	15/58	mg/kg-OC	540/700	2	2.7	0	0
Bis(2-ethylhexyl)phthalate	47/78	mg/kg-OC	1,300/1,900	8	11.0	3	4.1
Diethylphthalate	61/110	mg/kg-OC	200/200	0	0	0	0
Dimethyl phthalate	53/53	mg/kg-OC	71/160	0	0	0	0
Di-n-butyl phthalate	220/1700	mg/kg-OC	1,400/1,400	0	0	0	0
Di-n-Octyl phthalate	58/4500	mg/kg-OC	6,200/6,200	0	0	0	0
Hexachlorobenzene	0.38/2.3	mg/kg-OC	22/70	2	2.7	0	0
Hexachlorobutadiene	3.9/6.2	mg/kg-OC	11/120	0	0	0	0
Pentachlorophenol	360/650	µg/kg-dw	360/650	4	5.4	0	0
Phenol	420/1200	µg/kg-dw	420/1,200	0	0	0	0
PCBs							
PCBs (total)	12/65	mg/kg-OC	130/1,000	59	81	11	15.1
Metals							
Arsenic	57/93	mg/kg-dw	57/93 [1/]	12	16.4	10	13.7
Cadmium	5.1/6.7	mg/kg-dw	5.1/6.7 [1/]	0	0	0	0
Chromium	260/270	mg/kg-dw	260/270 [1/]	3	4.1	3	4.1
Copper	390/390	mg/kg-dw	390/390 [1/]	16	21.9	16	21.9
Lead	450/530	mg/kg-dw	450/530 [1/]	3	4.1	2	2.7
Mercury	0.41/0.59	mg/kg-dw	0.41/0.59 [1/]	32	44	24	33
Silver	6.1/6.1	mg/kg-dw	6.1/6.1[1/]	0	0	0	0
Zinc	410/960	mg/kg-dw	410/960 [1/]	17	23.3	3	4.1

Table 4-8.
Comparison of Surface Sample Results to the Sediment Management Standards (Page 3 of 3)

Parameter	SQS/CSL	Unit Basis	LAET/2LAET (µg/kg-dw)	Number Samples Exceeding SQS/LAET	Percent Exceeding SQS/LAET	Number Samples Exceeding CSL/2LAET	Percent Exceeding CSL/2LAET

Notes:
1/ Criteria are in mg/kg-dw.
For OC normalized SQS and CSL criteria where the percent OC in the sample is less than 0.5 percent the sample concentrations are compared to the LAET or 2LAET for SQS and CSL, respectively.
mg/kg-OC = milligram per kilogram organic carbon
mg/kg-dw = milligram per kilogram dry weight
µg/kg-dw = microgram per kilogram dry weight
CSL/2LAET = Cleanup Screening Level/Second Lowest Apparent Effects Threshold
HPAH = heavy weight polycyclic aromatic hydrocarbon
LPAH = light weight polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SQS/LAET = Sediment Quality Standard/Lowest Apparent Effects Threshold
SVOC = semivolatile organic compound

Table 4-9.
Subsurface Sediment Summary of Detected Parameters (Page 1 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
Metals							
Antimony	153	95.6	0.043	256	TT08-CS	19	0.04 - 0.05
Arsenic	160	100.0	1.11	374	TT08-CS	31	-
Cadmium	160	100.0	0.032	2.38	TT25-CS	0.36	-
Chromium	160	100.0	2.1	925	TT15-CS	66	-
Cobalt	138	100.0	2.07	31.7	TT17-CS	7.3	-
Copper	160	100.0	6.7	2620	TT08-CS	295	-
Lead	160	100.0	1.76	2200	M1	128	-
Mercury	152	95.0	0.0005	17.1	TT15-CS	1.2	0.0005 - 0.0005
Molybdenum	138	100.0	0.23	21	TT08-CS	2.5	-
Nickel	160	100.0	1.1	413	TT15-CS	28	-
Selenium	101	73.2	0.1	1.4	TT10-CS	0.53	0.1 - 0.5
Silver	147	91.9	0.015	1.42	TT08-CS	0.28	0.1 - 0.1
Thallium	138	100.0	0.023	0.25	TT17-CS	0.094	-
Vanadium	138	100.0	21.9	336	TT09-CS	51	-
Zinc	160	100.0	19.6	2680	TT08-CS	304	-
TBT							
Tributyltin	116	84.1	0.00021	9.1	TT09-CS	0.65	0.00007-4.5
PAHs							
1-Methylnaphthalene	34	24.6	0.0031	3.6	TT07-CS	0.29	0.0029 - 0.32
2-Methylnaphthalene	119	75.3	0.0018	1.6	D5	0.11	0.0015 - 0.27
Acenaphthene	133	84.2	0.0016	20	TT07-CS	0.60	0.0013 - 0.024
Acenaphthylene	122	77.2	0.002	1.9	SB1	0.13	0.0018 - 0.25
Anthracene	139	88.0	0.0021	16	D1	0.75	0.0018 - 0.024
Benzo(a)anthracene	142	89.9	0.0026	19	SB1	1.3	0.0019 - 0.024

Table 4-9.
Subsurface Sediment Summary of Detected Parameters (Page 2 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
Benzo(a)pyrene	140	88.6	0.0025	15	SB1	1.0	0.0021 - 0.024
Benzo(b)fluoranthene	124	89.9	0.004	16	TT08-CS	1.2	0.0033 - 0.0037
Benzo(g,h,i)perylene	136	86.1	0.0031	8.8	SB1	0.57	0.003 - 0.025
Benzo(k)fluoranthene	112	81.2	0.0045	4.7	TT08-CS	0.54	0.0032 - 0.0092
Benzofluoranthenes (total)	142	89.9	0.004	22	SB1	1.9	0.0033 - 0.024
Chrysene	143	90.5	0.0022	15	SB1; TT08-CS	1.4	0.0019 - 0.024
Dibenzo(a,h)anthracene	118	74.7	0.0029	4.2	SB1	0.21	0.0027 - 0.3
Fluoranthene	144	91.1	0.0036	58	TT25-CS	3.51	0.0029 - 0.024
Fluorene	126	79.7	0.0024	20	TT07-CS	0.62	0.0021 - 0.024
Indeno(1,2,3-cd)pyrene	138	87.3	0.0027	8.9	SB1	0.63	0.0025 - 0.025
Naphthalene	137	86.7	0.0017	6.9	D5	0.36	0.0017 - 0.27
Phenanthrene	155	98.1	0.0018	58	TT07-CS	2.2	0.0017 - 0.024
Pyrene	153	96.8	0.0018	39	TT25-CS	3.5	0.0017 - 0.024
Total cPAH	125	90.6	0.000022	17.22	TT08-CS	1.3	0.0033 - 0.0037
Total HPAH	153	96.8	0.0018	163.9	SB1	13	0.0033 - 0.024
Total LPAH	155	98.1	0.0018	107.42	TT07-CS	4.3	0.0023 - 0.024
Total PAH	136	98.6	0.002	215	TT08-CS	15	0.0033 - 0.0035
PCBs							
PCBs (total)	114	71.3	0.0041	9.62	TT15-CS	0.81	0.0022 - 0.2
Pesticides							
Aldrin	6	3.8	0.00031	0.01	TT08-CS	0.0041	0.00019 – 0.11
alpha-BHC	1	0.7	0.00064	0.00064	TT04-CS	0.00064	0.00032 – 0.19
alpha-Chlordane	1	0.6	0.0086	0.0086	TT17-CS	0.0086	0.00028 – 0.17
beta-BHC	8	5.8	0.00042	0.013	TT07-CS	0.0052	0.00037 – 0.22
delta-BHC	40	29.0	0.000085	0.01	TT08-CS	0.0025	0.000067 – 0.039

Table 4-9.
Subsurface Sediment Summary of Detected Parameters (Page 3 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
Dieldrin	9	5.6	0.00046	0.021	TT07-CS	0.007	0.00036 – 0.21
Endosulfan I	16	11.6	0.00062	0.083	TT17-CS	0.018	0.00021 – 0.12
Endosulfan II	14	10.1	0.00037	0.015	TT15-CS	0.0044	0.00024 – 0.14
Endosulfan Sulfate	30	21.7	0.00011	0.01	TT15-CS	0.0011	0.000097 – 0.056
Endrin	14	10.1	0.00029	0.029	TT15-CS	0.0088	0.00025 – 0.15
Endrin aldehyde	81	58.7	0.000068	0.066	TT17-CS	0.0065	0.000066 – 0.038
gamma-BHC	38	23.8	0.00028	0.012	TT07-CS	0.0042	0.00019 – 0.11
gamma-Chlordane	66	47.8	0.00012	0.2	TT17-CS	0.018	0.000078 – 0.045
Heptachlor	14	8.8	0.00014	0.0054	TT08-CS	0.017	0.000098 – 0.057
Heptachlor epoxide	43	31.2	0.00021	0.063	TT17-CS	0.010	0.00016 – 0.092
Methoxychlor	62	44.9	0.00019	0.029	TT07-CS	0.007	0.00013 – 0.071
Mirex	30	21.7	0.00015	0.014	TT14-CS	0.0043	0.00013 – 0.071
Nonachlor (cis)	77	55.8	0.00015	0.14	TT15-CS	0.010	0.00011 – 0.059
Nonachlor (trans)	30	21.7	0.00023	0.036	TT07-CS	0.0090	0.00011 – 0.063
o,p-DDD	79	57.2	0.00037	0.18	TT17-CS	0.033	0.00027 – 0.15
o,p-DDE	36	26.1	0.00051	0.082	TT15-CS	0.018	0.00028 – 0.17
o,p-DDT	78	56.5	0.0003	0.29	TT15-CS	0.033	0.00018 – 0.099
Oxychlordane	2	1.4	0.000066	0.0032	TT37-CS	0.0019	0.00046 – 0.26
p,p-DDD	80	58.0	0.00019	0.26	TT15-CS	0.015	0.00015 – 0.085
p,p-DDE	35	25.4	0.00022	0.016	TT15-CS	0.0059	0.00013 – 0.071
p,p-DDT	101	73.2	0.00014	0.47	TT15-CS	0.037	0.0000083 – 0.002
Total chlordane	56	40.6	0.00016	0.2	TT17-CS	0.021	0.00047 – 0.26
Total DDT	98	71.0	0.00014	1.02	TT15-CS	0.077	0.0003 – 0.0071
Toxaphene	57	41.3	0.015	5.2	TT15-CS	0.47	0.011 – 6.4
Other SVOCs							

Table 4-9.
Subsurface Sediment Summary of Detected Parameters (Page 4 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
1,2,4-Trichlorobenzene	1	0.6	0.28	0.28	SB1	0.28	0.001 - 0.14
1,2-Dichlorobenzene	2	1.3	0.0023	0.043	TT15-CS	0.023	0.0016 - 0.14
1,3-Dichlorobenzene	0	0.0	-	-	-	-	0.002 - 0.28
1,4-Dichlorobenzene	1	0.6	0.007	0.007	TT19-CS	0.0070	0.0024 - 0.28
2,4,5-Trichlorophenol	0	0.0	-	-	-	-	0.0037 - 0.22
2,4,6-Trichlorophenol	0	0.0	-	-	-	-	0.0022 - 0.14
2,4-Dichlorophenol	0	0.0	-	-	-	-	0.0022 - 0.14
2,4-Dimethylphenol	0	0.0	-	-	-	-	0.0067 - 0.4
2,4-Dinitrophenol	0	0.0	-	-	-	-	0.044 - 2.7
2,4-Dinitrotoluene	0	0.0	-	-	-	-	0.0035 - 0.21
2,6-Dinitrotoluene	0	0.0	-	-	-	-	0.0035 - 0.21
2-Chloronaphthalene	0	0.0	-	-	-	-	0.0044 - 0.27
2-Chlorophenol	0	0.0	-	-	-	-	0.0021 - 0.13
2-Methylphenol	2	1.3	0.027	0.14	SB1	0.084	0.0042 - 0.25
2-Nitroaniline	0	0.0	-	-	-	-	0.0033 - 0.2
2-Nitrophenol	0	0.0	-	-	-	-	0.0032 - 0.19
3,3-Dichlorobenzidine	0	0.0	-	-	-	-	0.0046 - 0.27
3-Nitroaniline	0	0.0	-	-	-	-	0.0032 - 0.19
4,6-Dinitro-o-cresol	0	0.0	-	-	-	-	0.0021 - 0.13
4-Bromophenyl phenyl ether	0	0.0	-	-	-	-	0.0018 - 0.19
4-Chloro-3-methylphenol	0	0.0	-	-	-	-	0.0026 - 0.16
4-Chloroaniline	0	0.0	-	-	-	-	0.0026 - 0.16
4-Chlorophenyl phenyl ether	0	0.0	-	-	-	-	0.0025 - 0.15
4-Methylphenol	24	15.2	0.0063	0.73	SB1	0.064	0.0036 - 0.26
4-Nitroaniline	1	0.7	0.047	0.047	TT06-CS	0.047	0.0042 - 0.25

Table 4-9.
Subsurface Sediment Summary of Detected Parameters (Page 5 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)
4-Nitrophenol	0	0.0	-	-	-	-	0.037 - 2.2
Aniline	20	14.5	0.0029	0.039	TT32-CS	0.012	0.0019 - 0.11
Benzoic acid	1	0.6	0.008	0.008	D4	0.0080	0.11 - 7
Benzyl alcohol	3	1.9	0.0055	0.0064	TT33-CS	0.0061	0.0046 - 0.27
bis(2-chloroethoxy)methane	0	0.0	-	-	-	-	0.0016 - 0.095
bis(2-chloroethyl)ether	0	0.0	-	-	-	-	0.003 - 0.18
bis(2-chloroisopropyl)ether	0	0.0	-	-	-	-	0.0015 - 0.088
bis(2-ethylhexyl)phthalate	139	88.0	0.0029	11	SB1	0.50	0.0023 - 0.26
Butyl benzyl phthalate	12	7.6	0.0022	0.092	TT14-CS	0.019	0.0019 - 0.28
Dibenzofuran	126	79.7	0.0018	15	TT07-CS	0.37	0.0016 - 0.024
Diethylphthalate	6	3.8	0.0055	0.081	TT04-CS	0.024	0.0043 - 0.28
Dimethyl phthalate	4	2.5	0.0027	0.011	TT19-CS	0.0059	0.0022 - 0.28
Di-n-butyl phthalate	89	56.3	0.0036	2.1	TT18-CS	0.079	0.0033 - 0.36
Di-n-octyl phthalate	8	5.1	0.036	0.16	D3	0.089	0.0015 - 0.28
Hexachlorobenzene	1	0.6	0.0031	0.0031	TT25-CS	0.0031	0.000097 - 0.28
Hexachlorobutadiene	2	1.3	0.00084	0.0011	TT04-CS	0.00097	0.0006 - 0.28
Hexachlorocyclopentadiene	0	0.0	-	-	-	-	0.019 - 1.1
Hexachloroethane	1	0.6	0.047	0.047	D1	0.047	0.0027 - 0.56
Isochrones	1	0.7	0.17	0.17	TT07-CS	0.17	0.002 - 0.12
Nitrobenzene	0	0.0	-	-	-	-	0.0025 - 0.15
N-Nitrosodimethylamine	6	4.2	0.0042	0.27	D5	0.10	0.0075 - 0.45
N-Nitroso-di-n-propylamine	0	0.0	-	-	-	-	0.0039 - 0.24
N-Nitrosodiphenylamine	0	0.0	-	-	-	-	0.0027 - 0.16
Pentachlorophenol	12	7.6	0.013	0.92	TT17-CS	0.21	0.011 - 1.4
Phenol	66	41.8	0.0025	6.1	TT17-CS	0.16	0.0024 - 0.55

Table 4-9.
Subsurface Sediment Summary of Detected Parameters (Page 6 of 6)

Parameter	Detection Summary						
	Number Detected	Frequency of Detection Percent (%)	Minimum (mg/kg-dw)	Maximum (mg/kg-dw)	Location of Maximum detected	Mean (mg/kg-dw)	Range of Reporting Limits (mg/kg-dw)

Notes:
Detected results include estimated concentrations below the sample reporting limits.
HPAH = heavy-weight polycyclic aromatic hydrocarbon
LPAH = light-weight polycyclic aromatic hydrocarbon
mg/kg-dw = milligram per kilogram dry weight
PCB = polychlorinated biphenyl
SVOC = semivolatile organic compound

Table 4-10.
Comparison of the Subsurface Sediment Results to the Sediment Management Standards (Page 1 of 3)

Parameter	SQS/CSL	Unit Basis	LAET/2LAET (µg/kg-dw)	Number Samples Exceeding SQS/LAET	Percent Exceeding SQS/LAET	Number Samples Exceeding CSL/2LAET	Percent Exceeding CSL/2LAET
PAHs							
Acenaphthylene	16/57	mg/kg-OC	500/730	9	5.6	9	5.6
Benzo(a)anthracene	110/270	mg/kg-OC	1,300/1,600	45	28	29	16
Benzo(a)pyrene	99/210	mg/kg-OC	1,600/3,000	38	24	24	15
Benzofluoranthenes (total)	230/450	mg/kg-OC	3,200/3,600	34	21	23	14
Benzo(g,h,i)perylene	31/78	mg/kg-OC	6,760/720	49	31	30	19
Chrysene	110/460	mg/kg-OC	1,400/2,800	46	29	21	12
Dibenzo(a,h)anthracene	12/33	mg/kg-OC	230/540	53	33	26	16
Fluoranthene	160/1,200	mg/kg-OC	1,700/2,500	55	34	26	16
Indeno(1,2,3-cd)pyrene	34/88	mg/kg-OC	600/690	26	16	7	4.4
Phenanthrene	100/480	mg/kg-OC	1,500/5,400	52	33	32	20
Pyrene	1,000/1,400	mg/kg-OC	2,600/3,300	26	16	16	10
Acenaphthene	16/57	mg/kg-OC	500/730	56	35	36	23
Anthracene	220/1,200	mg/kg-OC	960/440	28	18	3	1.9
Fluorene	23/79	mg/kg-OC	1,700/2,500	49	31	32	20
Naphthalene	99/170	mg/kg-OC	2,100/2,400	23	14	18	6.3
2-Methylnaphthalene	38/68	mg/kg-OC	670/1,400	16	10	12	7.5
Total LPAH	370/780	mg/kg-OC	5,200/13,000	47	29	36	23
Total HPAH	960/5,300	mg/kg-OC	12,000/17,000	53	33	19	12
Other SVOCs							
1,2-Dichlorobenzene	2.3/2.3	mg/kg-OC	35/50	0	0	0	0
1,4-Dichlorobenzene	3.1/9	mg/kg-OC	110/120	0	0	0	0
1,2,4-Trichlorobenzene	0.81/1.8	mg/kg-OC	31/51	0	0	0	0
2-Methylphenol	63/63	µg/kg-dw	63/63	0	0	0	0
4-Methylphenol	670/670	µg/kg-dw	670/670	0	0	0	0
2,4-Dimethylphenol	29/29	µg/kg-dw	29/29	0	0	0	0

Table 4-10.
Comparison of the Subsurface Sediment Results to the Sediment Management Standards (Page 2 of 3)

Parameter	SQS/CSL	Unit Basis	LAET/2LAET (µg/kg-dw)	Number Samples Exceeding SQS/LAET	Percent Exceeding SQS/LAET	Number Samples Exceeding CSL/2LAET	Percent Exceeding CSL/2LAET
Benzyl alcohol	57/73	µg/kg-dw	57/73	0	0	0	0
Benzoic Acid	650/650	µg/kg-dw	650/650	0	0	0	0
Butyl benzyl phthalate	4.9/64	mg/kg-OC	63/900	0	0	0	0
Dibenzofuran	15/58	mg/kg-OC	540/700	48	30	28	18
Bis(2-ethylhexyl)phthalate	47/78	mg/kg-OC	1,300/1,900	38	24	29	16
Diethylphthalate	61/110	mg/kg-OC	200/200	0	0	0	0
Dimethyl phthalate	53/53	mg/kg-OC	71/160	0	0	0	0
Di-n-butyl phthalate	220/1,700	mg/kg-OC	1,400/1,400	0	0	0	0
Di-n-Octyl phthalate	58/4500	mg/kg-OC	6,200/6,200	2	1.3	0	0
Pentachlorophenol	360/690	µg/kg-dw	22/70	4	2.6	0	0
Phenol	420/1,200	µg/kg-dw	11/120	0	0	0	0
PCBs							
PCBs (total)	12/65	mg/kg-OC	130/1,000	74	46	36	23
Metals							
Arsenic	57/93	mg/kg-dw	57/93 [1/]	27	17	15	9.4
Cadmium	5.1/6.7	mg/kg-dw	5.1/6.7 [1/]	0	0	0	0
Chromium	260/270	mg/kg-dw	260/270 [1/]	7	4.4	7	4.4
Copper	390/390	mg/kg-dw	390/390 [1/]	29	18	29	18
Lead	450/530	mg/kg-dw	450/530 [1/]	14	8.8	11	6.9
Mercury	0.41/0.59	mg/kg-dw	0.41/0.59 [1/]	52	33	43	27
Silver	6.1/6.1	mg/kg-dw	6.1/6.1 [1/]	0	0	0	0
Zinc	410/960	mg/kg-dw	410/960 [1/]	33	21	17	11

Table 4-10.
Comparison of the Subsurface Sediment Results to the Sediment Management Standards (Page 3 of 3)

Parameter	SQS/CSL	Unit Basis	LAET/2LAET (µg/kg-dw)	Number Samples Exceeding SQS/LAET	Percent Exceeding SQS/LAET	Number Samples Exceeding CSL/2LAET	Percent Exceeding CSL/2LAET

Notes:
1/ Criteria are in mg/kg-dw.
For OC normalized SQS and CSL criteria where the percent OC in the sample is less than 0.5 percent. The sample concentrations are compared to the LAET or 2LAET for SQS and CSL, respectively.
µg/kg dw = microgram per kilogram dry weight
CSL/2LAET = Cleanup Screening Level/Second Lowest Apparent Effects Threshold
HPAH = heavy-weight polycyclic aromatic hydrocarbon
LPAH = light-weight polycyclic aromatic hydrocarbon
mg/kg dw = milligram per kilogram dry weight
mg/kg OC = milligram per kilogram organic carbon
PCB = polychlorinated biphenyl
SQS/LAET = Sediment Quality Standard/Lowest Apparent Effects Threshold
SVOC = semivolatile organic compound

Table 4-11.
Porewater Data Summary (Page 1 of 2)

Parameter	Number Samples Detected	Maximum concentration Detected (µg/L)	Minimum concentration Detected (µg/L)
Antimony	7	41.4	1.27
Arsenic	7	56.8	6.82
Cadmium	7	0.218	0.044
Chromium	6	2.11	0.57
Cobalt	7	1.71	0.218
Copper	7	25.6	5.19
Lead	7	11	3.6
Mercury	6	0.21	0.05
Molybdenum	7	119	27.5
Nickel	1	7.34	3.85
Vanadium	7	13.1	7.1
Zinc	1	6.28	6.28
PCBs (total)	6	0.4	0.028
PCB-1254	6	0.23	0.013
PCB-1260	6	0.17	0.026
Aldrin	1	1.2	1.2
alpha-BHC	2	1.7	0.83
alpha-Chlordane	1	2.3	2.3
Endosulfan II	1	2.8	2.8
gamma-Chlordane	2	7.7	2.5
o,p'-DDT	5	25	3.1
p,p'-DDD	2	6	4.2
p,p'-DDE	1	6.6	6.6
p,p'-DDT	5	73	13
Total DDT	5	104	16.1
Total chlordane	2	7.7	4.8
2-Methylnaphthalene	7	0.066	0.031
4-Chloro-3-methylphenol	7	0.17	0.037
4-Methylphenol	7	4.5	0.065
Acenaphthene	7	0.23	0.012
Acenaphthylene	7	0.25	0.045
Anthracene	7	0.47	0.07
Benzo(a)anthracene	7	0.31	0.07
Benzo(a)pyrene	7	0.69	0.13
Benzo(b)fluoranthene	7	1	0.23
Benzo(g,h,i)perylene	7	0.3	0.087
Benzo(k)fluoranthene	7	0.69	0.096
Benzofluoranthenes (total)	7	1.69	0.23
Benzoic acid	4	12	4.1

Table 4-11.
Porewater Data Summary (Page 2 of 2)

Parameter	Number Samples Detected	Maximum concentration Detected (µg/L)	Minimum concentration Detected (µg/L)
bis(2-ethylhexyl)phthalate	7	1.4	0.52
Butyl benzyl phthalate	7	0.16	0.066
Chrysene	7	0.53	0.097
Dibenzo(a,h)anthracene	7	0.16	0.039
Dibenzofuran	7	0.067	0.017
Diethylphthalate	7	0.54	0.15
Di-n-butyl phthalate	1	1.7	1.7
Fluoranthene	7	0.61	0.13
Fluorene	7	0.14	0.016
Hexachlorobenzene	7	6	0.071
Indeno(1,2,3-cd)pyrene	7	0.35	0.11
Isophorone	7	0.043	0.011
Naphthalene	7	0.13	0.038
Pentachlorophenol	7	0.79	0.036
Phenanthrene	7	0.25	0.069
Phenol	7	160	17
Pyrene	7	0.89	0.22
Total HPAH	7	5.462	1.347
Total LPAH	7	1.433	0.222
Total PAH	7	6.895	1.71
Butyltin	4	0.033	0.02
Dibutyltin	5	0.21	0.076
Tetrabutyltin	7	0.014	0.0015
Tributyltin	7	1.9	0.02
Total Organic Carbon	7	19.7	14.2

Notes:
µg/L = microgram per liter
HPAH = heavy-weight polycyclic aromatic hydrocarbon
LPAH = light-weight polycyclic aromatic hydrocarbon
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl

Table 4-12.
Summary of Detected Compounds in Collected Clam Tissue Samples (Page 1 of 2)

Parameter	Number Detects	Minimum Detected (mg/kg-ww)	Maximum Detected (mg/kg-ww)
2-Methylnaphthalene	3	0.00061	0.0027
Acenaphthene	3	0.00091	0.013
Acenaphthylene	3	0.00096	0.0031
Anthracene	3	0.004	0.04
Benzo(a)anthracene	3	0.017	0.17
Benzo(a)pyrene	3	0.012	0.14
Benzo(b)fluoranthene	3	0.02	0.21
Benzo(g,h,i)perylene	3	0.0071	0.029
Benzo(k)fluoranthene	3	0.007	0.065
Benzofluoranthenes (total)	3	0.027	0.275
Chrysene	3	0.03	0.19
Dibenzo(a,h)anthracene	3	0.0015	0.011
Fluoranthene	3	0.078	0.59
Fluorene	3	0.0016	0.023
Indeno(1,2,3-cd)pyrene	3	0.0077	0.036
Naphthalene	3	0.00074	0.0062
Phenanthrene	3	0.017	0.18
Pyrene	3	0.058	0.44
Total HPAH	3	0.2383	1.7777
Total LPAH	3	0.02521	0.2551
Total cPAH	3	0.0181	0.189
Total PAH	3	0.26351	2.0328
Dibenzofuran	3	0.0007	0.011
Hexachlorobenzene	1	0.00097	0.00097
Hexachlorobutadiene	3	0.00084	0.0022
Aldrin	1	0.00051	0.00051
alpha-Chlordane	2	0.00022	0.001
beta-BHC	3	0.00098	0.0017
delta-BHC	1	0.001	0.001
Dieldrin	3	0.00097	0.001
Endosulfan I	2	0.00017	0.00027
Endosulfan II	1	0.001	0.001
Endosulfan sulfate	2	0.00097	0.001
gamma-BHC	1	0.00055	0.00055
gamma-Chlordane	3	0.00075	0.0021
Heptachlor	2	0.00073	0.001
Heptachlor epoxide	3	0.00078	0.00088
Methoxychlor	1	0.0033	0.0033
Nonachlor (cis)	3	0.00097	0.0011
Nonachlor (trans)	2	0.00021	0.00027
Total chlordane	2	0.0014	0.0021

Table 4-12.
Summary of Detected Compounds in Collected Clam Tissue Samples (Page 2 of 2)

Parameter	Number Detects	Minimum Detected (mg/kg-ww)	Maximum Detected (mg/kg-ww)
Total DDT	3	0.00013	0.0009
Toxaphene	2	0.025	0.05
PCBs (total)	4	0.017	0.066
Butyltin	3	0.0018	0.0046
Dibutyltin	3	0.0099	0.02
Tributyltin	3	0.049	0.072
Dioxins/Furans TEQ (ng/kg-ww)	3	0.0677	0.154
Antimony	4	0.33	0.771
Arsenic	4	17	22.7
Cadmium	4	0.17	1.2
Chromium	4	4.32	7.71
Cobalt	4	1.93	2.34
Copper	4	122	264
Lead	4	13.5	27
Mercury	4	0.027	0.151
Molybdenum	4	2.53	5.92
Nickel	4	3.52	8.66
Selenium	4	3.35	4.2
Silver	4	0.518	1.3
Thallium	4	0.016	0.081
Vanadium	4	5.11	7.4
Zinc	4	198	423

Notes:
HPAH = heavy-weight polycyclic aromatic hydrocarbon
LPAH = light-weight polycyclic aromatic hydrocarbon
mg/kg-ww = milligram per kilogram wet weight
ng/kg-ww = nanogram per kilogram wet weight
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
TEQ = toxicity equivalent quotient

Table 4-13.
Summary of Compound Concentrations in Surface Sediment Samples for Compounds Detected in Clam Tissue Samples (Page 1 of 2)

Parameter	Number Detects	Minimum Detected (mg/kg-dw)	Maximum Detected (mg/kg-dw)
2-Methylnaphthalene	4	1.8	35
Acenaphthene	4	1.6	140
Acenaphthylene	4	1.7	160
Anthracene	4	5.2	410
Benzo(a)anthracene	4	21	1,700
Benzo(a)pyrene	4	24	1,200
Benzo(b)fluoranthene	4	38	2,300
Benzo(g,h,i)perylene	4	18	660
Benzo(k)fluoranthene	4	12	750
Benzofluoranthenes (total)	4	50	3,050
Chrysene	4	21	2,600
Dibenzo(a,h)anthracene	4	4.2	190
Fluoranthene	4	49	12,000
Fluorene	4	2.1	160
Indeno(1,2,3-cd)pyrene	4	17	760
Naphthalene	4	4.9	96
Phenanthrene	4	17	1,200
Pyrene	4	79	6,800
Total HPAH	4	283.2	28,430
Total LPAH	4	32.5	1,975
Total cPAH	4	34.7	1,720
Total PAH	4	315.7	29,782
Dibenzofuran	4	1.7	76
Hexachlorobenzene	1	0.64	0.64
Hexachlorobutadiene	1	2.8	2.8
Aldrin	0	NA	NA
alpha-Chlordane	2	0.32	0.48
beta-BHC	0	NA	NA
delta-BHC	0	NA	NA
Dieldrin	0	NA	NA
Endosulfan I	0	NA	NA
Endosulfan II	0	NA	NA
Endosulfan sulfate	0	NA	NA
gamma-BHC	0	NA	NA
gamma-Chlordane	1	11	11
Heptachlor	0	NA	NA
Heptachlor epoxide	0	NA	NA
Methoxychlor	0	NA	NA
Nonachlor (cis)	0	NA	NA

Table 4-13.
Summary of Compound Concentrations in Surface Sediment Samples for Compounds Detected in Clam Tissue Samples (Page 2 of 2)

Parameter	Number Detects	Minimum Detected (mg/kg-dw)	Maximum Detected (mg/kg-dw)
Nonachlor (trans)	0	NA	NA
Total chlordane	2	0.32	11.48
Total DDT	4	1.3	22.4
Toxaphene	0	NA	NA
PCBs (total)	4	30	610
Butyltin	4	3.4	630
Dibutyltin	4	0.36	110
Tributyltin	4	15	1,800
Dioxins/Furans TEQ (ng/kg-dw)	4	0.687	13.8
Antimony	4	5.35	14.2
Arsenic	4	7.92	44.3
Cadmium	4	0.222	0.647
Chromium	4	23.8	93
Cobalt	4	3.46	9.33
Copper	4	28.3	299
Lead	4	48.6	135
Mercury	4	0.117	0.873
Molybdenum	4	2.11	5.28
Nickel	4	11.3	29.9
Selenium	4	0.3	1
Silver	4	0.072	0.502
Thallium	4	0.041	0.267
Vanadium	4	24.5	65
Zinc	4	115	290

Notes:
HPAH = heavy weight polycyclic aromatic hydrocarbon
LPAH = light weight polycyclic aromatic hydrocarbon
mg/kg-dw = milligram per kilogram dry weight
ng/kg-dw = nanogram per kilogram wet weight
PAH = polycyclic aromatic hydrocarbon
PCBs = polychlorinated biphenyl
TEQ = toxicity equivalent quotient

Table 4-14.
Reference Sediment Data Sets

Reference Data Set ID		Source of Data	Description of Data and Usage
"Bold Study" Sediment		EPA OSV Bold Survey 2009 (EPA, 2009a)	DMMP agencies collected 70 surface sediment samples at locations throughout Puget Sound. Samples were analyzed for dioxins/furans, PCBs and DMMP contaminants including PAHs and trace metals. The 95 UCL was determined for the 6 risk-driver contaminants with reported data.
Elliott Bay Sediment		Ecology Elliott Bay Data 2007 (Ecology, 2009a)	Ecology collected surface sediment samples from Elliott Bay and grouped them into three general categories.
	Basin	Ecology, 2009a	Basin area (2 samples). The maximum concentration for the 6 risk-drivers with reported data was used as the 95 UCL.
	Urban	Ecology, 2009a	Urban Bay area (13 samples). The 95 UCL was determined for the 6 risk-driver chemicals that had data reported.
	Harbor	Ecology, 2009a	Harbor area (15 samples). The 95 UCL was determined for the 6 risk-driver chemicals with reported data.
SQS		Sediment Quality Standard from the Washington State Sediment Management Standards (WAC 173-204)	Washington State promulgated sediment standards for the protection of benthic invertebrates.
CSL		Cleanup Screening Level from the Washington State Sediment Management Standards (WAC 173-204)	Washington State promulgated cleanup screening levels and minimum cleanup levels for the use in evaluating sediment sites.
RBTC		Site-specific risk based threshold concentrations (Section 9)	The lowest of the site-specific calculated risk-based concentrations for the Lockheed West Site.

Notes:
95 UCL = 95th percent upper confidence limit
CSL = cleanup screening level
DMMP = Dredge Material Management Program
PBC = polychlorinated biphenyl
PAH = polycyclic aromatic hydrocarbon
SQS = Sediment Quality Standard
RBTC = risk-based threshold concentration
WAC = Washington Administrative Code

Table 4-15.
Summary of Reference Data Sets, Risk-Based Concentrations, and Sediment Standards for the Lockheed West Site Risk Drivers

Parameter	RBTC	Analytical Reporting Limits 1/	"Bold Study"	Elliott Bay			SQS	CSL
				Basin 2/	Urban	Harbor		
Metals								
Arsenic	0.000023	1.0	7	9.13	8.44	73.4	57	93
Copper	114	1.0	24.9	41.1	48.9	112	390	390
Lead	10	1.0	10.9	26.9	47	66.9	450	530
Mercury	0.41	0.02	0.101	0.175	0.438	0.335	0.41	0.59
Organics								
cPAHs	0.00022	0.003	0.009	0.125	0.757	1.21	1.1 3/	3.0 3/
Total PCBs	0.00011	0.005	0.002 4/, 5/	0.048	0.119	0.355	0.13 3/	1.0 3/
Tributyltin	0.15	NA	NA	NA	NA	NA	1.335 6/	NA

Notes:
All concentrations in milligrams per kilogram dry weight.
1/ Analytical reporting limits are based on the "Bold Study" CRQL (EPA 2008a). For PCBs the Aroclor reporting limit is used.
2/ Value is the maximum detected result for the two samples in the defined region.
3/ SQS and CSL values are for benzo(a)pyrene.
4/ Total PCB result is for the sum of congeners as all Aroclor data were ND for Aroclors 1221 – 1260.
5/ Total PCB value is dry weight equivalent (LAET).
6/ Value for tributyltin is the West Waterway Confirmational Number.
cPAH = carcinogenic polycyclic aromatic hydrocarbon
CSL = Cleanup Screening Level
LAET = lowest apparent effects threshold
NA = analyte not analyzed
ND = not detected
PCB = polychlorinated biphenyl
RBTC = risk-based threshold concentration
SQS = Sediment Quality Standard

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Figure 4-1 Upland and Shoreline Survey Areas

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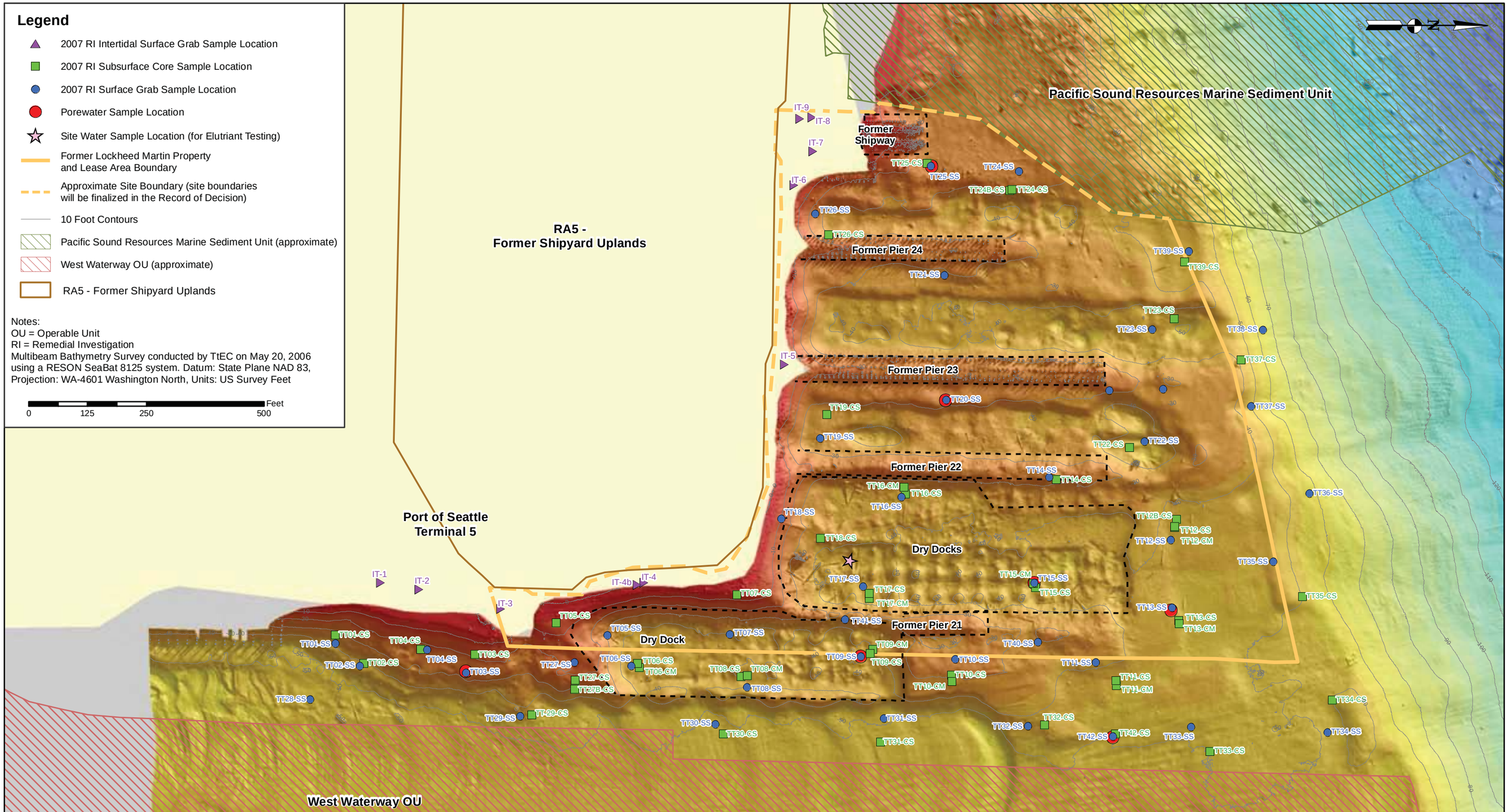

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Figure 4-2 Remedial Investigation Sediment Sampling Locations

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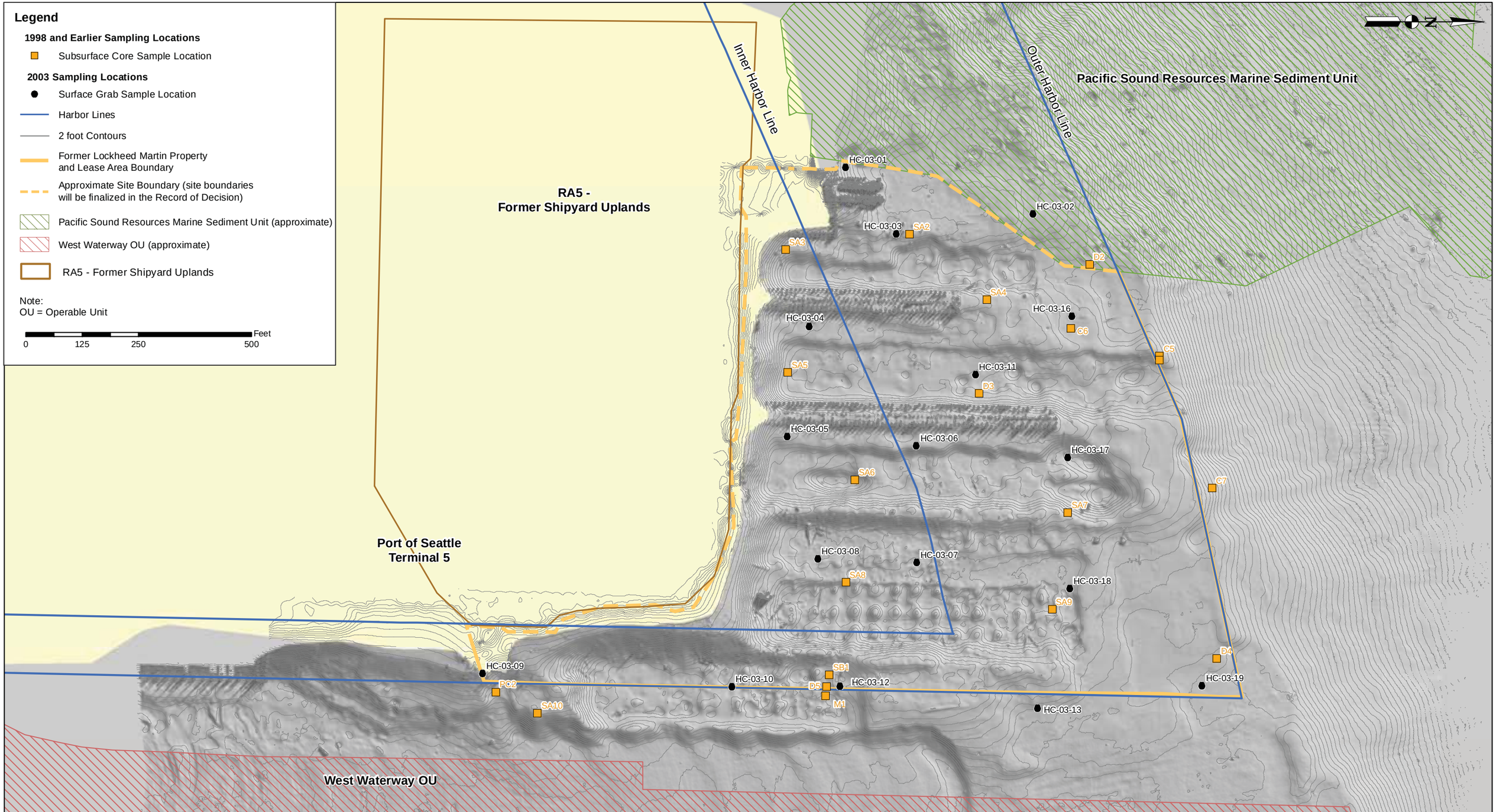

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Figure 4-3
1998 and Earlier Subsurface Cores and
2003 Surface Sediment Sampling Locations

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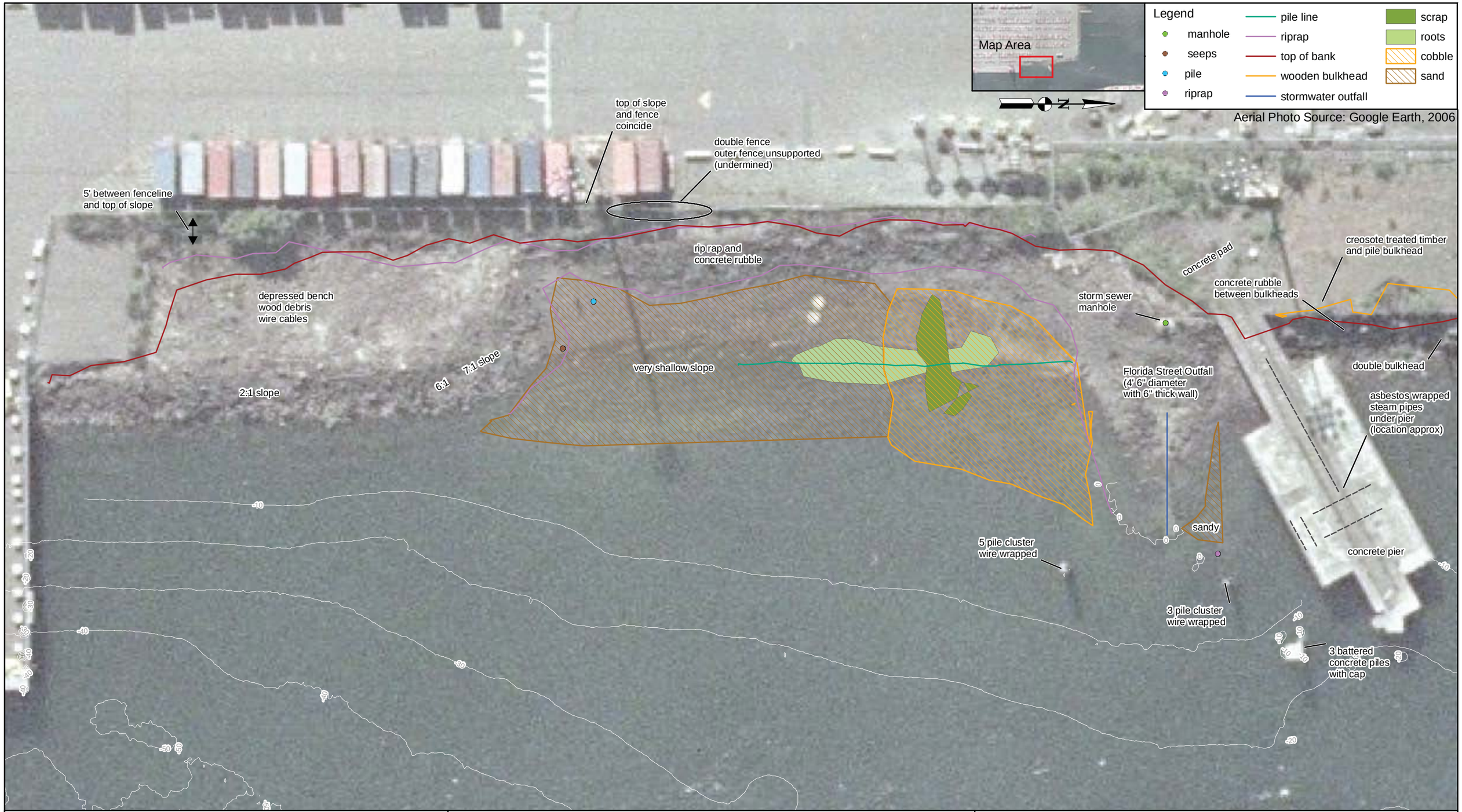

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Figure 4-4
Shoreline Survey Observations
Map 1

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Figure 4-5
Shoreline Survey Observations
Map 2

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Figure 4-6
Shoreline Survey Observations
Map 3

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Figure 4-7
Shoreline Survey Observations
Map 4

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Seattle, WA

Figure 4-8
Shoreline Survey Observations
Map 5

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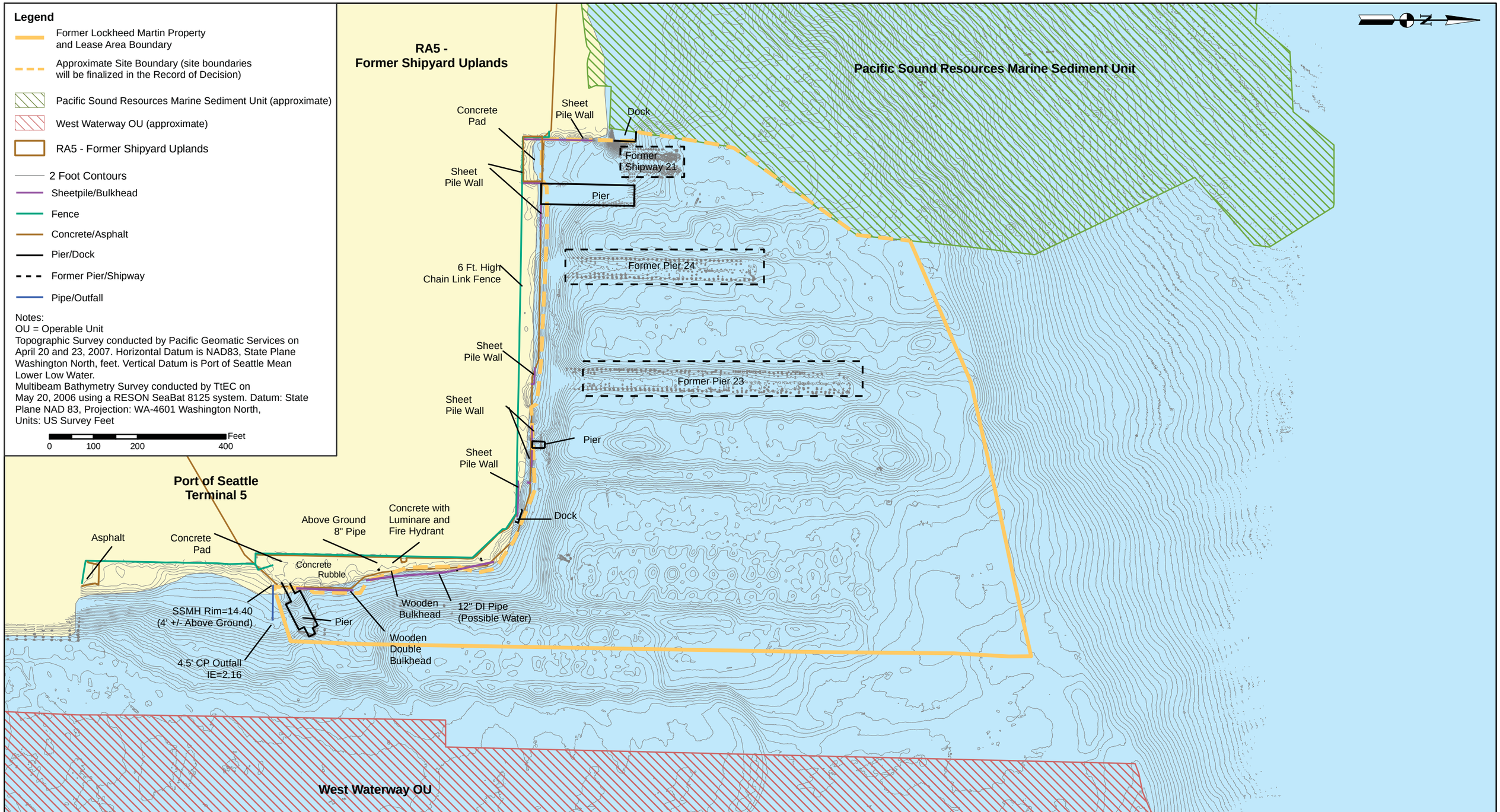

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Figure 4-9 Intertidal Topography and Bathymetry Contours

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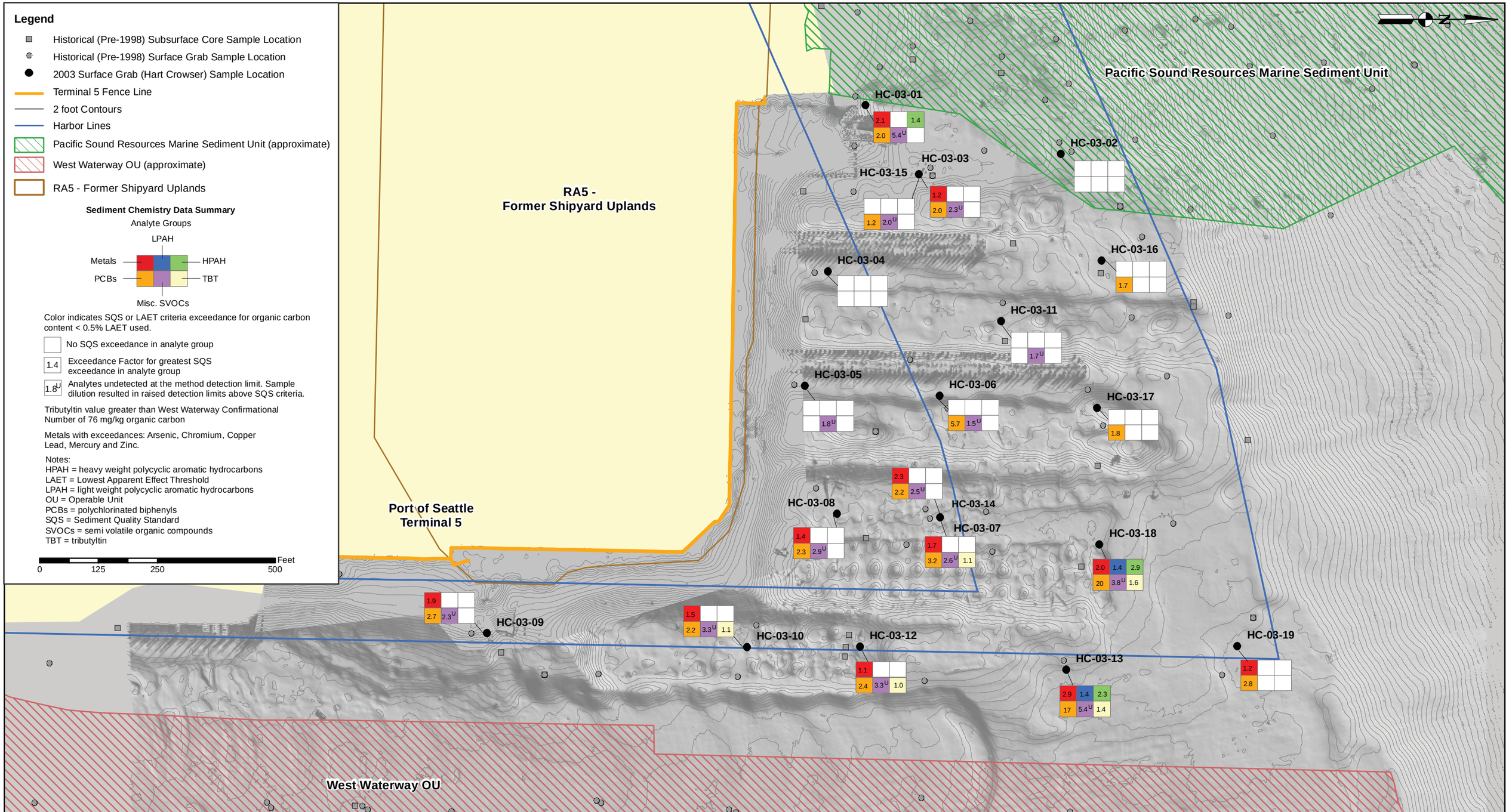

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Figure 4-10
Exceedances of Sediment Quality Standards in Surface Sediment Samples from 2003 (Pre-Remedial Investigation Data)

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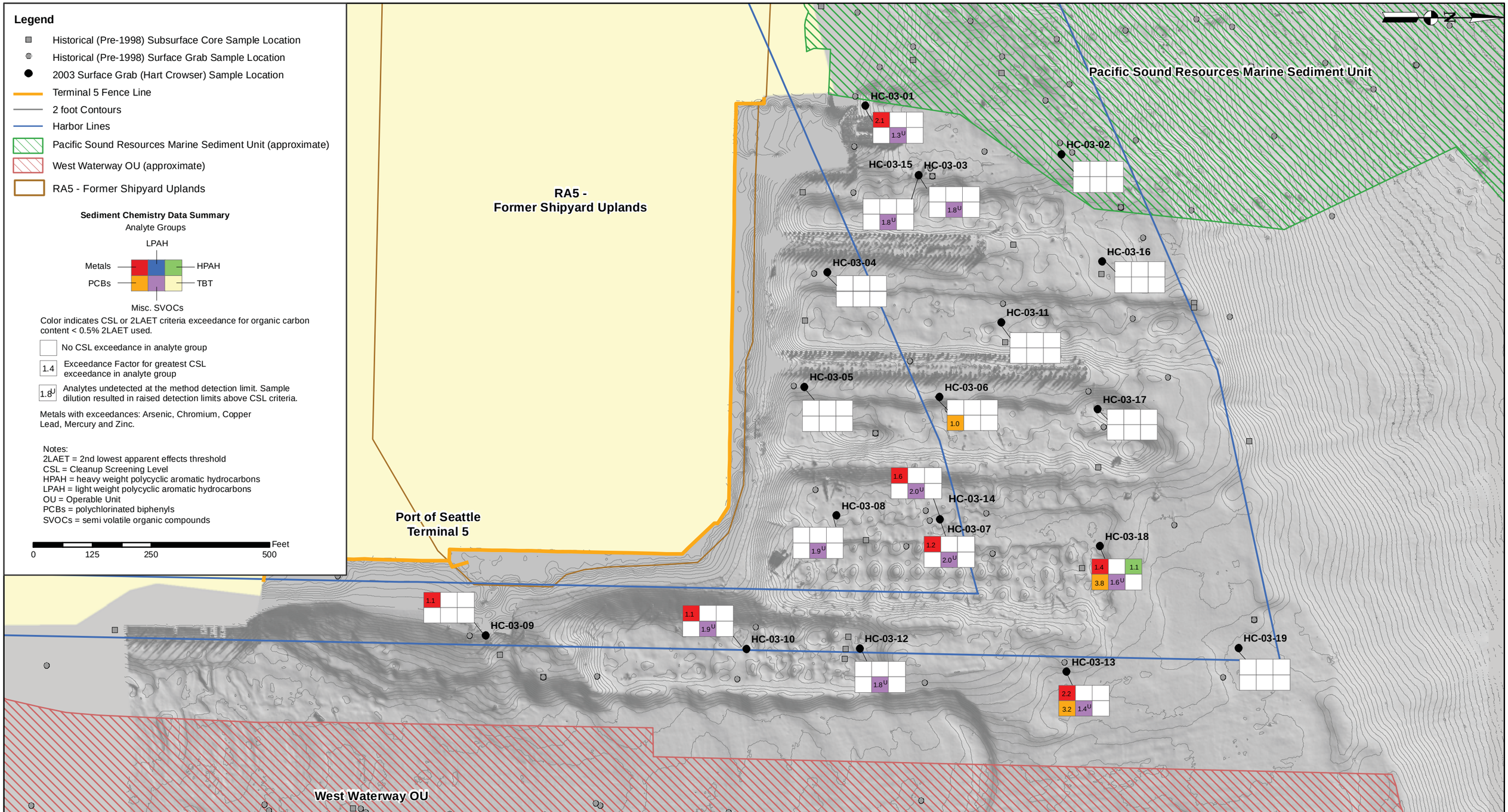

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Figure 4-11 Exceedances of Cleanup Screening Levels in Surface Sediment Samples from 2003 (Pre-Remedial Investigation Data)

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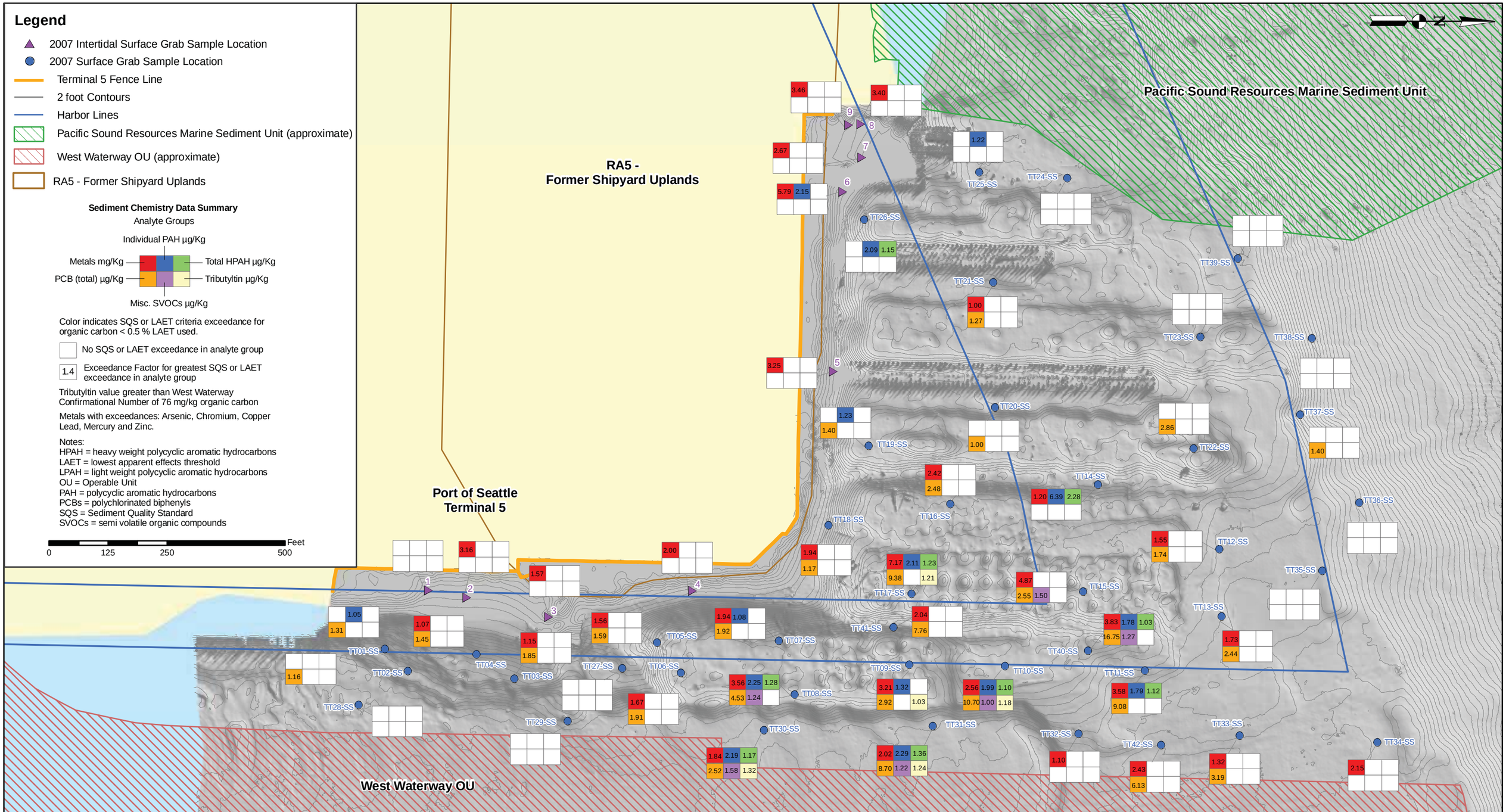

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Figure 4-12
Exceedances of Sediment Quality Standards in Surface Sediment Samples from 2007 (Remedial Investigation Data)

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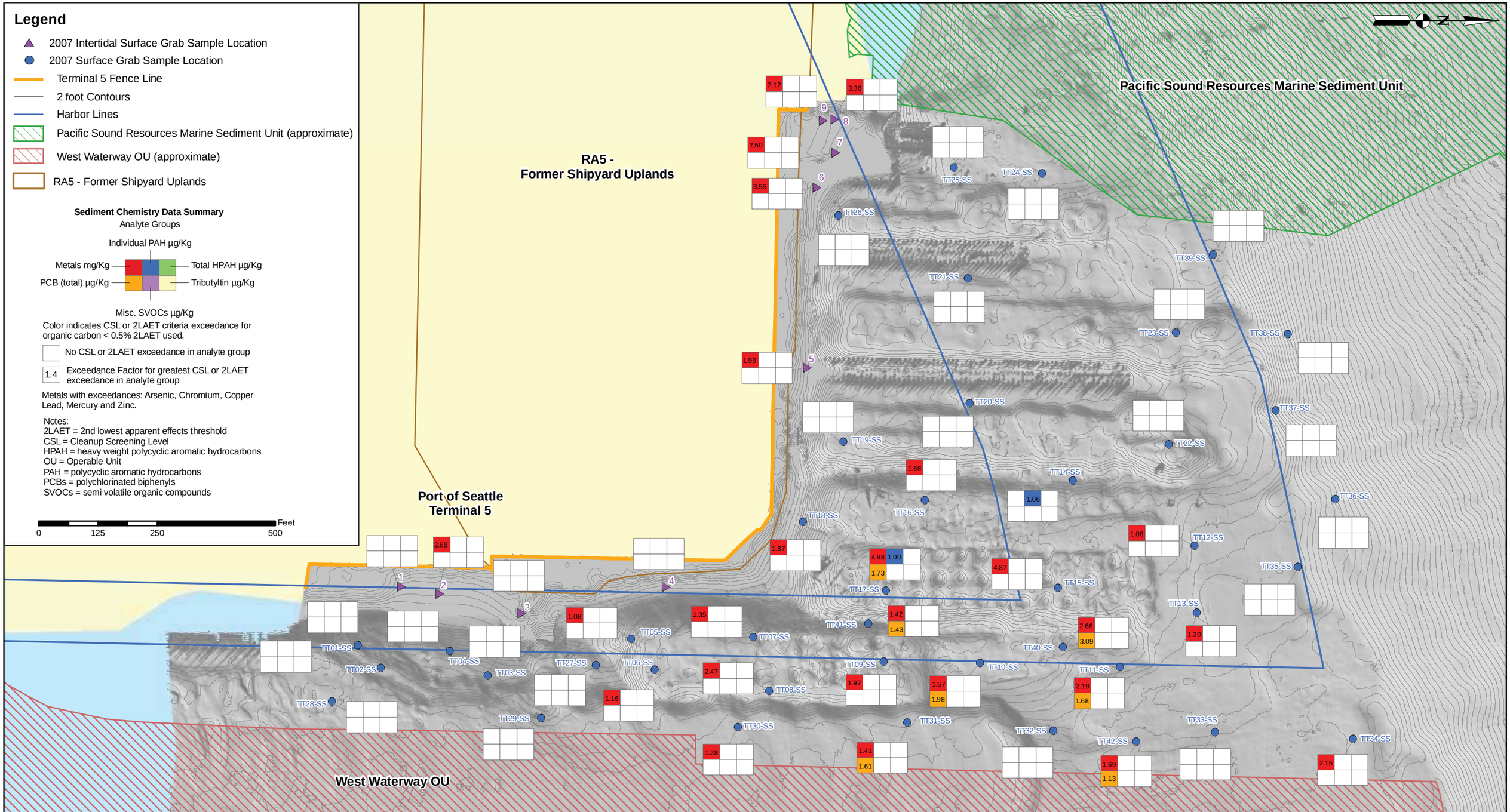

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Figure 4-13
Exceedances of Cleanup Screening Levels in Surface Sediment Samples from 2007 (Remedial Investigation Data)

Z:\Pdrive\Projects_2006\Lockheed\maps\RIFS_Report\Figure4-13_CSL_surface_2007.mxd

Legend

- Historical (Pre-1998) Sampling Locations (Enviros 1990, Hartman 1991, Parametrix 1993)
- Terminal 5 Fence Line
- 2 foot Contours
- Harbor Lines
- Pacific Sound Resources Marine Sediment Unit (approximate)
- West Waterway OU (approximate)
- RA5 - Former Shipyard Uplands

Sediment Chemistry Data Summary

Analyte Groups

Depth Interval	Metals	LPAH	HPAH	PCBs	Misc. SVOCs	Tributyltin
0 - 2 ft						

Color indicates SQS or LAET criteria exceedance for organic carbon <0.5% LAET used.

- No SQS or LAET exceedance in analyte group
- NR No values reported for analyte group
- 1.4 Exceedance Factor for greatest SQS or LAET exceedance in analyte group
- 1.1^{U} Analytes undetected at the method detection limit. Sample dilution resulted in raised detection limits above criteria

Metals with exceedances: Arsenic, Chromium, Copper Lead, Mercury and Zinc.

Notes:
HPAH = heavy weight polycyclic aromatic hydrocarbons
LAET = lowest apparent effects threshold
LPAH = light weight polycyclic aromatic hydrocarbons
OU = Operable Unit
SQS = Sediment Quality Standard
SVOCs = semi volatile organic compounds

0 125 250 500 Feet

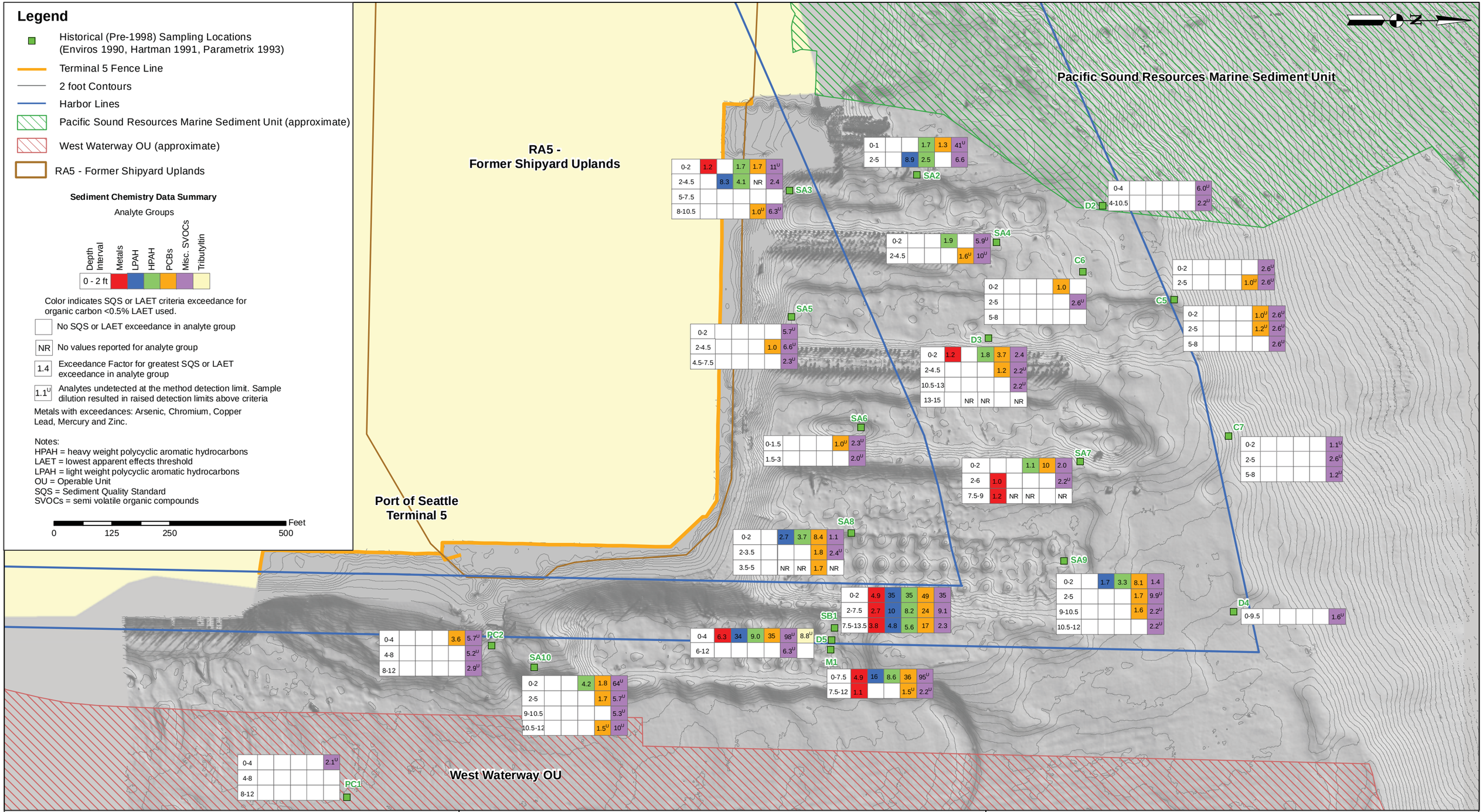

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Figure 4-14
Exceedances of Sediment Quality Standards 1998 and Earlier Subsurface Samples (Pre-Remedial Investigation Data)

Z:\Pdrive\Projects_2006\Lockheed\maps\RIFS_Report\Figure4-14_SQS_subsurface_1998.mxd

Legend

- Historical (Pre-1998) Sampling Locations (Enviros 1990, Hartman 1991, Parametrix 1993)
- Terminal 5 Fence Line
- 2 foot Contours
- Harbor Lines
- Pacific Sound Resources Marine Sediment Unit (approximate)
- West Waterway OU (approximate)
- RA5 - Former Shipyard Uplands

Sediment Chemistry Data Summary

Analyte Groups

Depth Interval	Metals	LPAH	HPAH	PCBs	Misc. SVOCs	Tributyltin
0 - 2 ft						

Color indicates CSL or 2LAET criteria exceedance for organic carbon < 0.5% 2LAET used.

- No CSL or 2LAET exceedance in analyte group
- NR No values reported for analyte group
- 1.4 Exceedance Factor for greatest CSL or 2LAET exceedance in analyte group
- 1.1^{U} Analytes undetected at the method detection limit. Sample dilution resulted in raised detection limits above criteria

Metals with exceedances: Arsenic, Chromium, Copper Lead, Mercury and Zinc.

Notes:
2LAET = 2nd lowest apparent effects threshold
CSL = Cleanup Screening Level
HPAH = heavy weight polycyclic aromatic hydrocarbons
LPAH = light weight polycyclic aromatic hydrocarbons
OU = Operable Unit
PCBs = polychlorinated biphenyls
SVOCs = semi volatile organic compounds

0 125 250 500 Feet

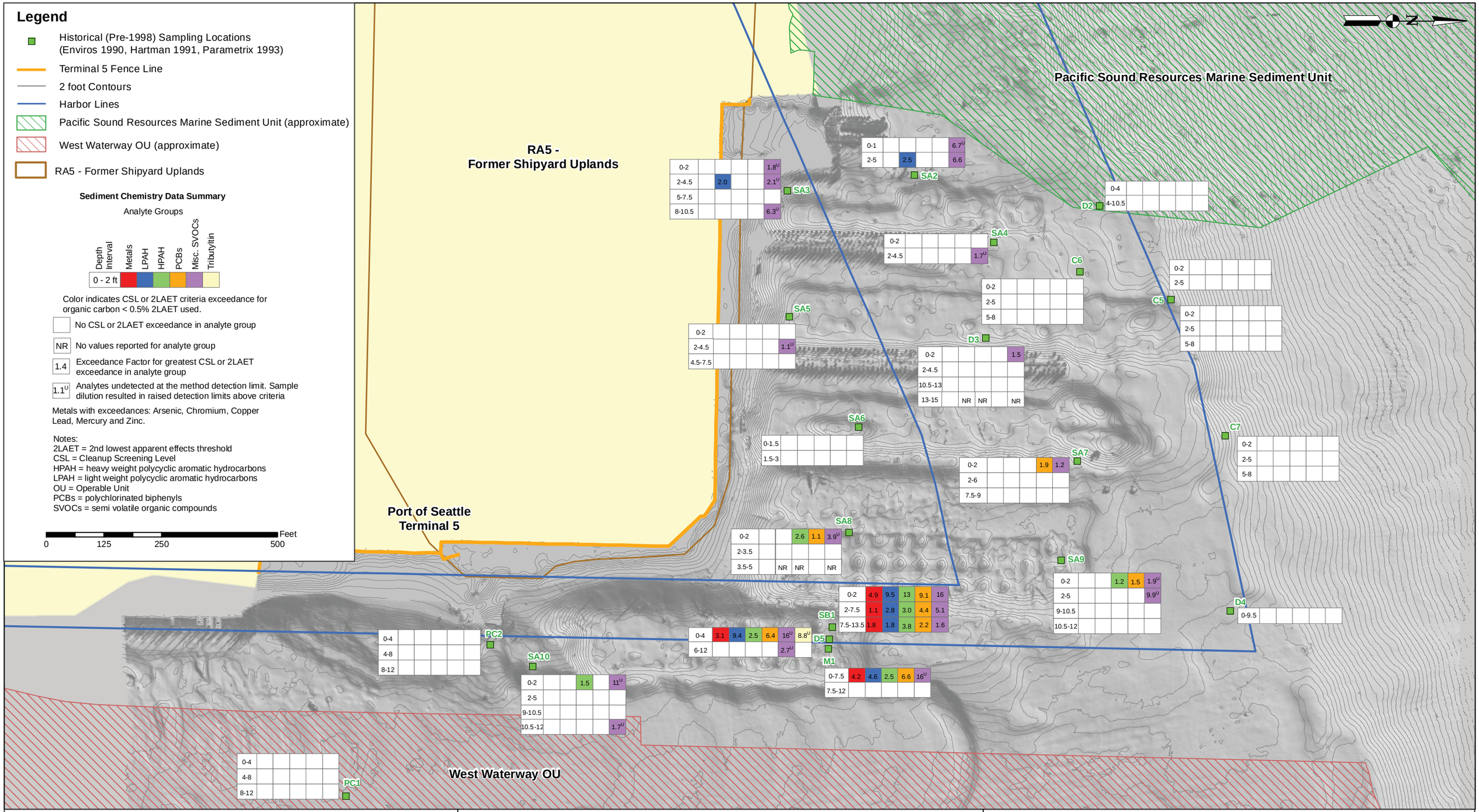

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Figure 4-15 Exceedances of Cleanup Screening Level 1998 and Earlier Subsurface Samples (Pre-Remedial Investigation Data)

Z:\Pdrive\Projects_2006\Lockheed\maps\RIFS_Report\Figure4-15_CSL_subsurface_1998.mxd

Legend

- Remedial Investigation Sampling Location with Exceedance
- Remedial Investigation Sampling Location with no SQS Exceedance
- Terminal 5 Fence Line
- 2 foot Contours
- Harbor Lines
- Pacific Sound Resources Marine Sediment Unit (approximate)
- West Waterway OU (approximate)
- RA5 - Former Shipyard Uplands

Sediment Chemistry Data Summary

Analyte Groups

Depth Interval	Metals	LPAH	HPAH	PCBs	Misc. SVOCs	Tributyltin
0 - 2 ft						

Color indicates SQS or LAET criteria exceedance for organic carbon <0.5% LAET used.

No SQS or LAET exceedance in analyte group

1.4 Exceedance Factor for greatest SQS or LAET exceedance in analyte group

1.1^{U} Analytes undetected at the method detection limit. Sample dilution resulted in raised detection limits above criteria

Tributyltin value greater than West Waterway Confirmational Number of 76 mg/kg organic carbon

Misc. SVOCs include chlorinated benzenes, phenols, phthalates and dibenzofuran

Metals with exceedances: Arsenic, Chromium, Copper Lead, Mercury and Zinc.

Notes:
LAET = lowest apparent effects threshold
HPAH = heavy weight polycyclic aromatic hydrocarbons
LPAH = light weight polycyclic aromatic hydrocarbons
OU = Operable Unit
SQS = Sediment Quality Standard
PCBs = polychlorinated biphenyls
SVOCs = semi volatile organic compounds

0 125 250 500 Feet

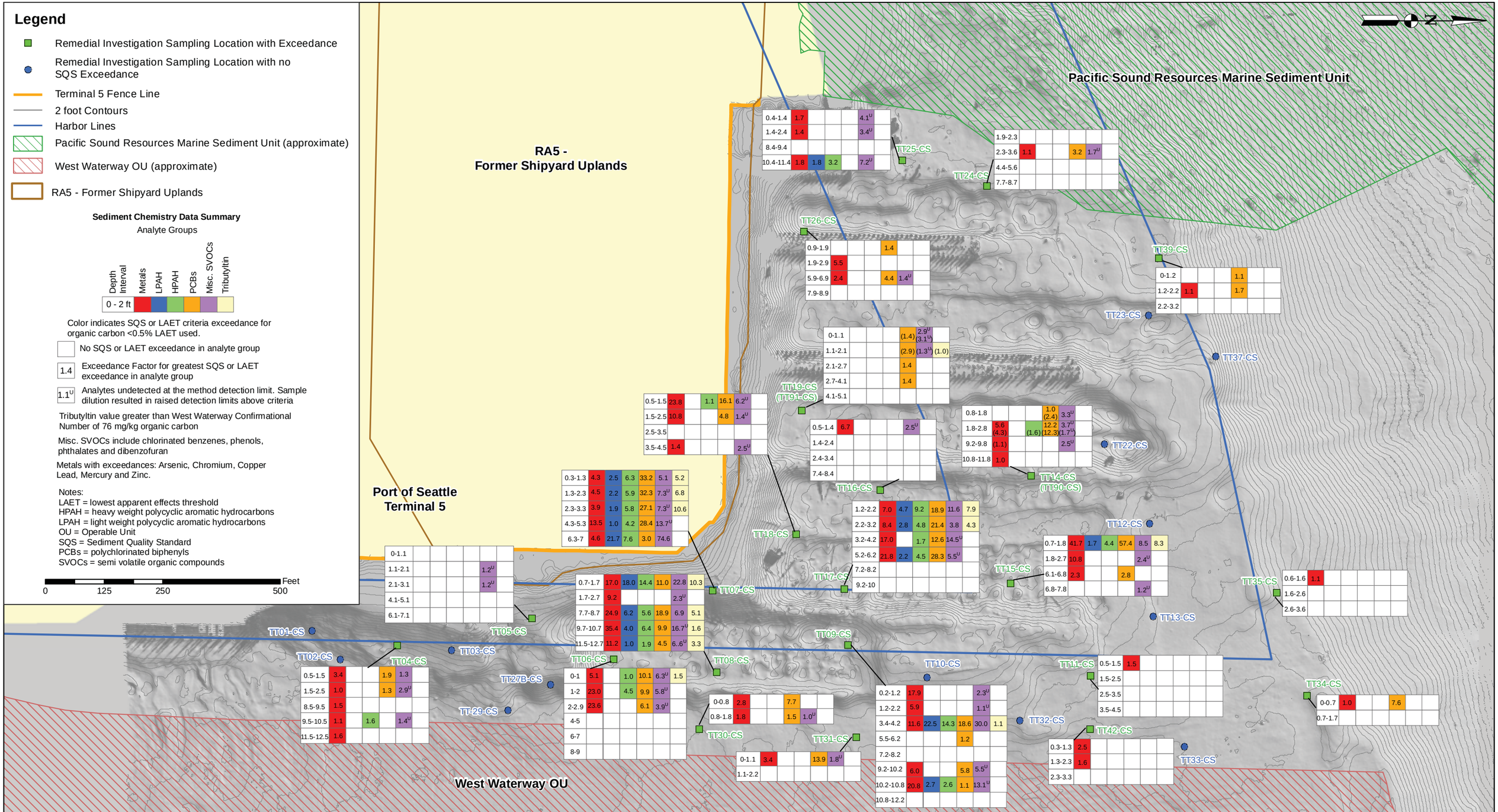

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Figure 4-16 Exceedances of Sediment Quality Standards in Subsurface Sediment Samples from 2007 (Remedial Investigation Data)

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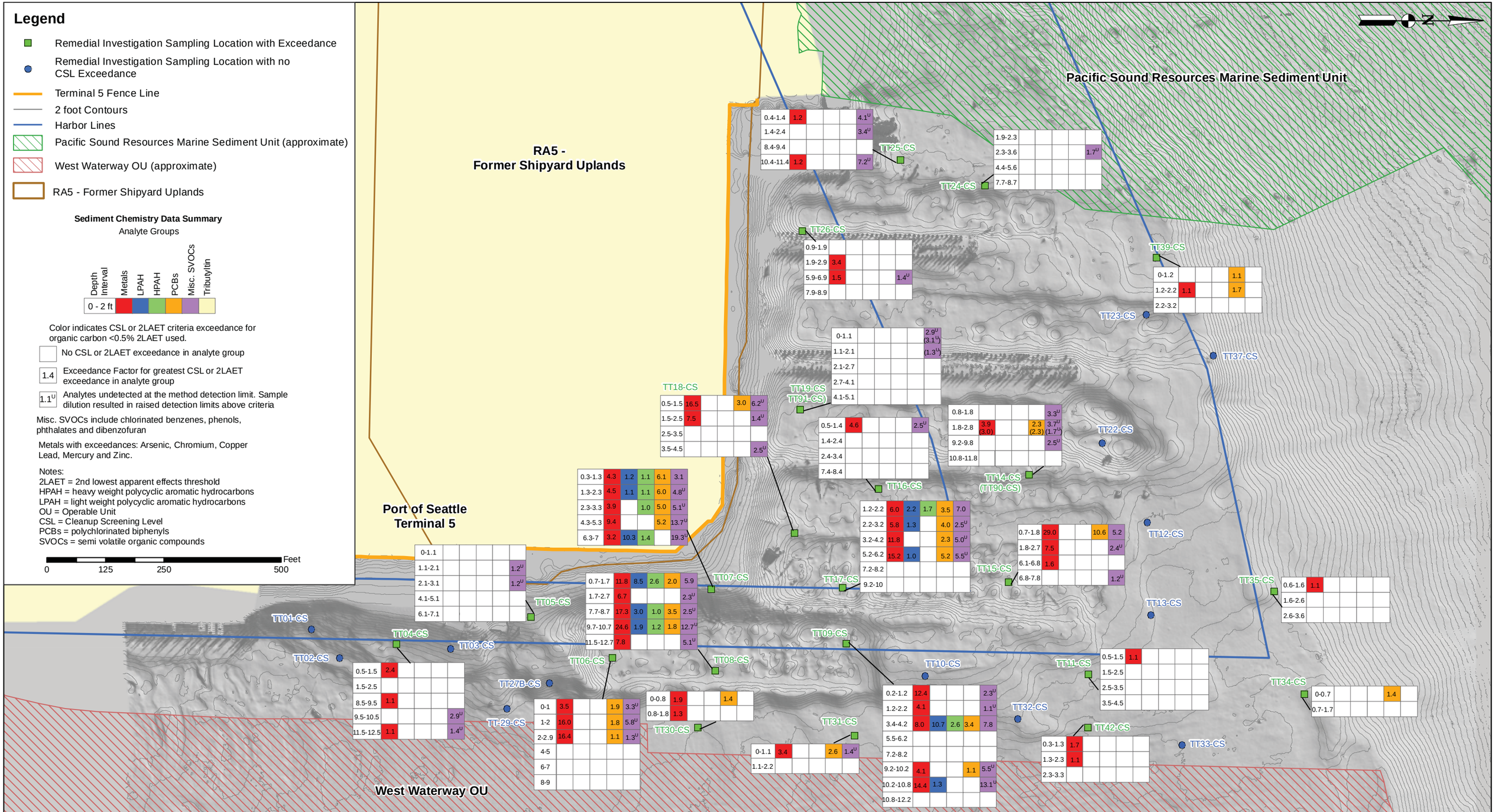

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Figure 4-17
Exceedances of Cleanup Screening Levels in Subsurface Sediment Samples from 2007 (Remedial Investigation Data)

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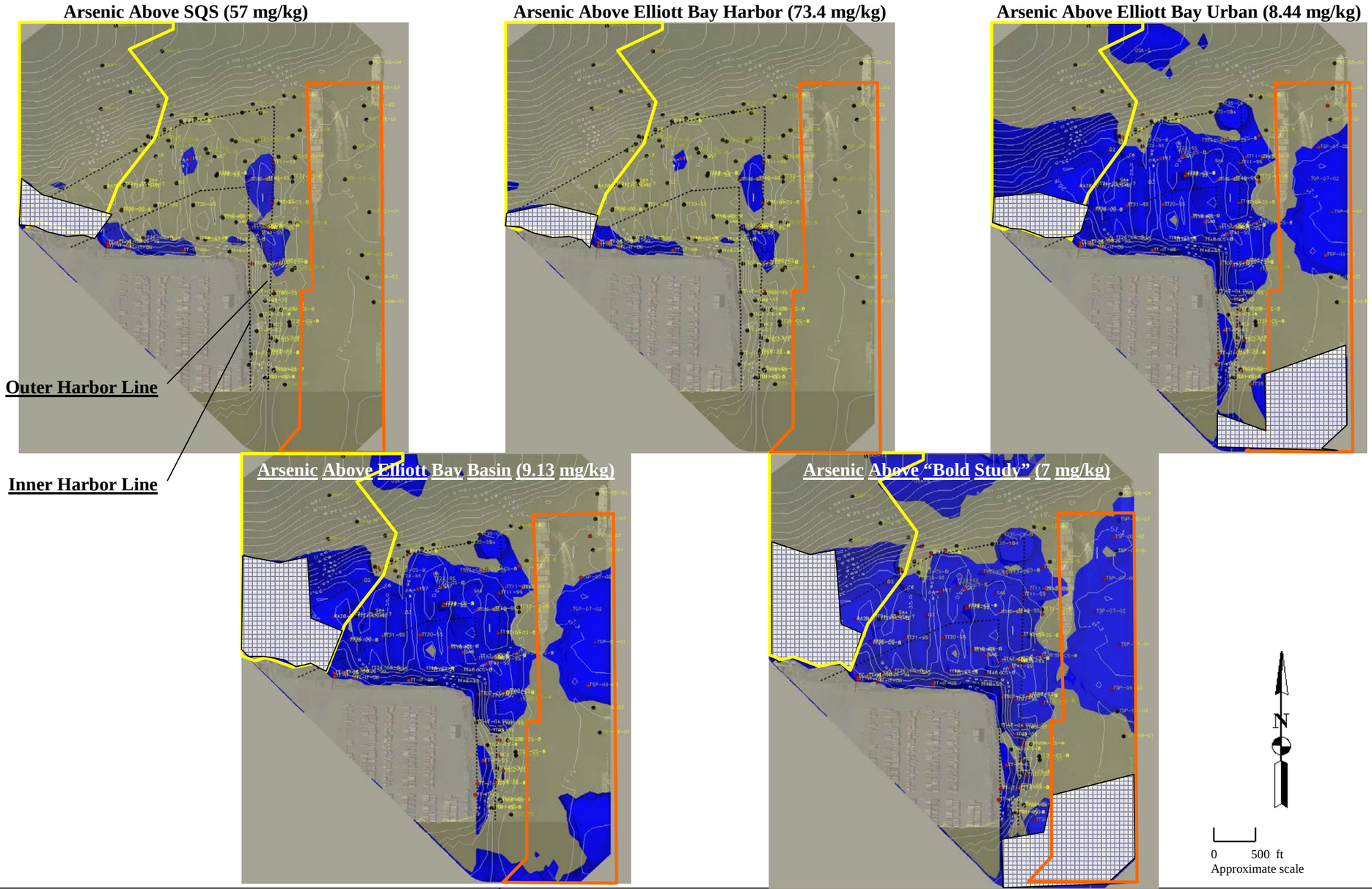

Legend:

- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)
- Sample Location
- Location with concentration above criteria
- Area where the estimated concentration is highly uncertain due to limited data.

Notes:

1) Criteria are the SQS, Upper 95th UCL of the Elliott Bay Harbor, Urban and Deep Basin areas and the "Bold Study" data

2) Area colored blue is the estimated area where the sediment concentration exceeds the comparison level.

3) Locations colored red are where the measured concentration exceeds the comparison level.

4) Some data points in Elliott Bay, beyond the extent of the figures are used in the visualization model.

SQS = Sediment Quality Standard
UCL = Upper Confidence Limit

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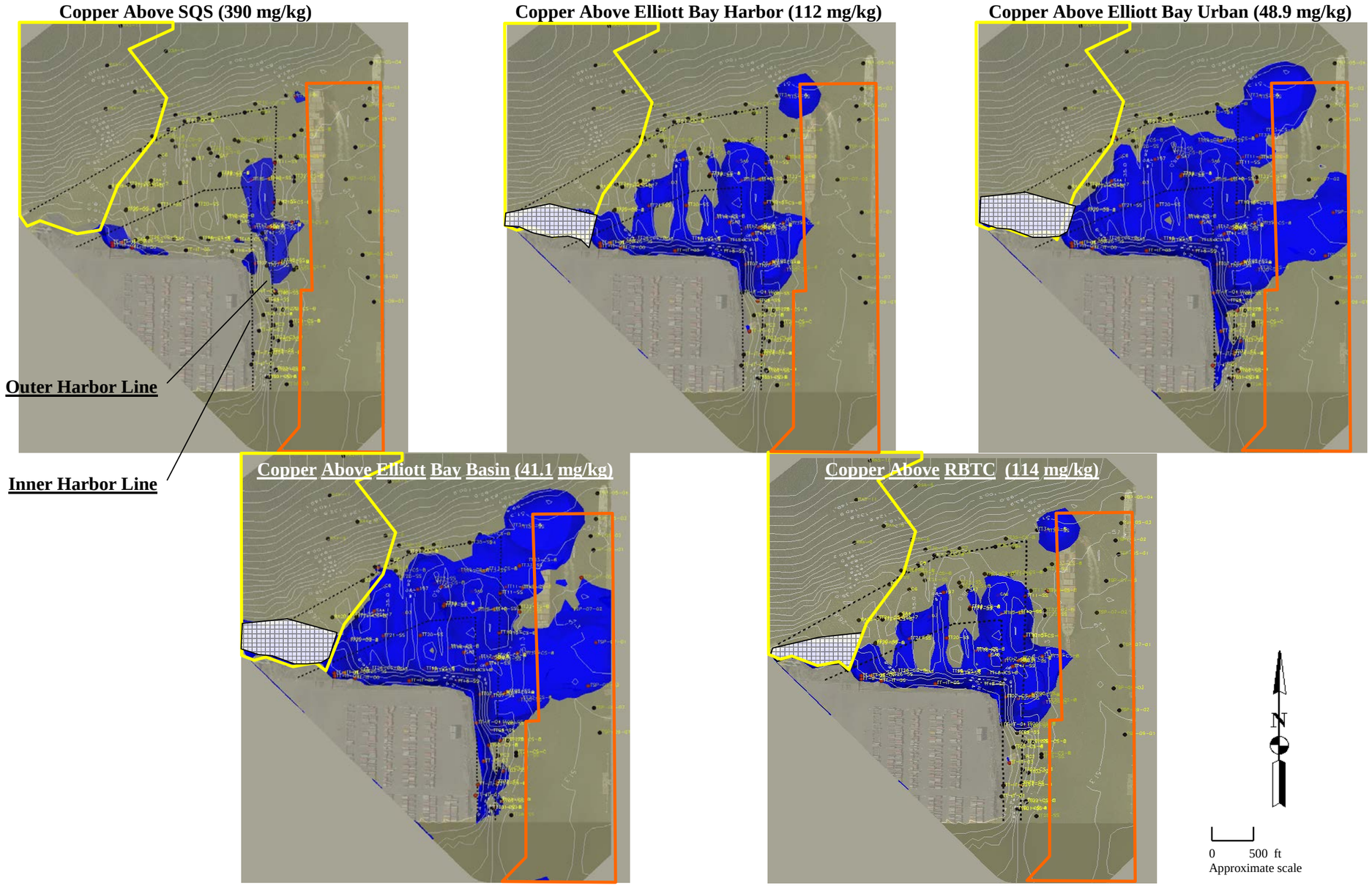
Figure 4-18
Estimated Arsenic Concentrations in Surface and Subsurface Sediment Above the Screening Levels



Legend:

- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)
- Sample Location
- Location with concentration above criteria
- Area where the estimated concentration is highly uncertain due to limited data.

Notes:

1) Criteria are the SQS, Upper 95th UCL of the Elliott Bay Harbor, Urban and Deep Basin areas and the RBTC

2) Area colored blue is the estimated area where the sediment concentration exceeds the comparison level.

3) Locations colored red are where the measured concentration exceeds the comparison level.

4) Some data points in Elliott Bay, beyond the extent of the figures are used in the visualization model.

SQS = Sediment Quality Standard
UCL = Upper Confidence Limit
RBTC = Risk Based Threshold Concentration

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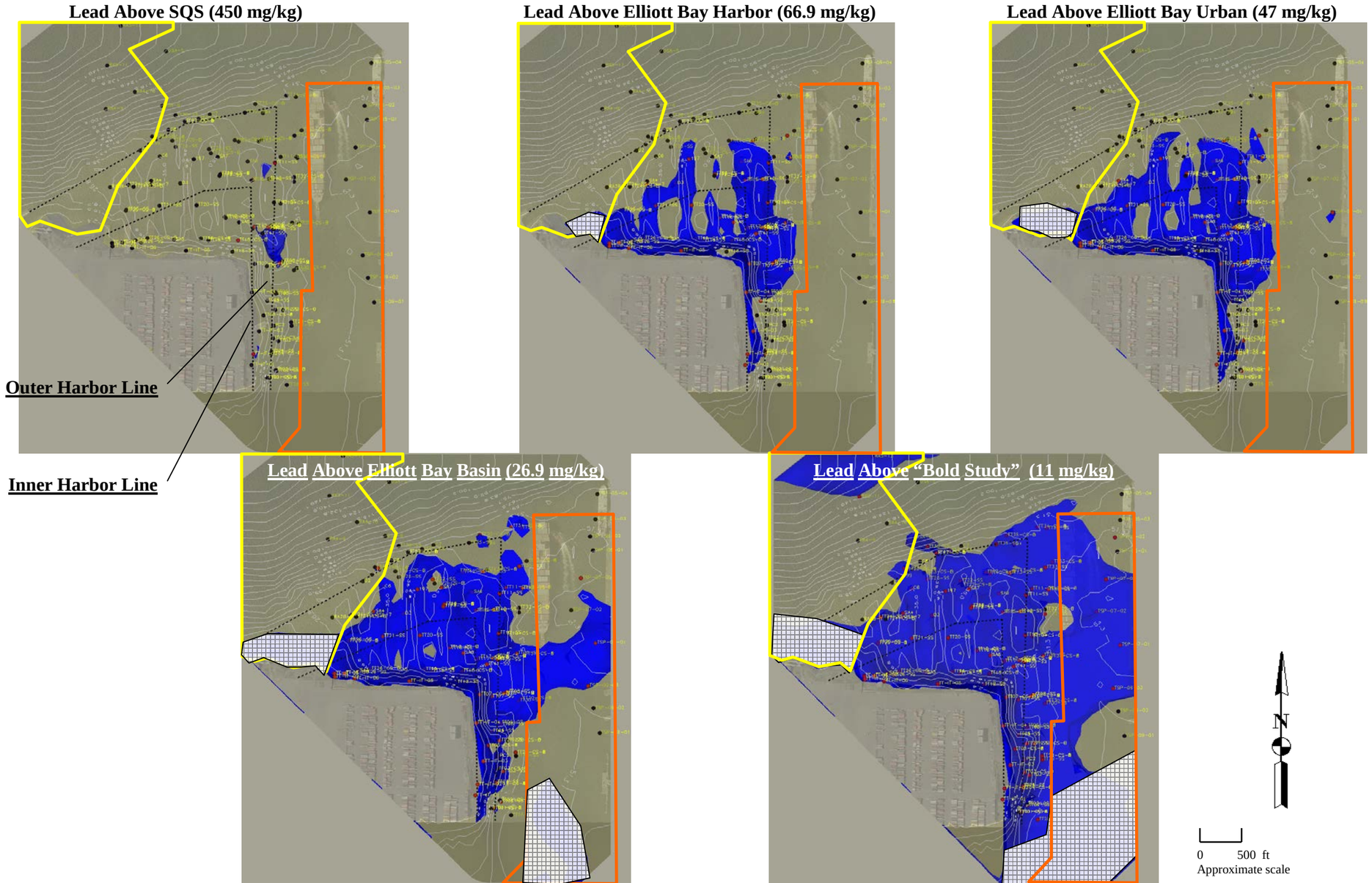
Figure 4-19
Estimated Copper Concentrations in Surface and Surface Sediment Above the Screening Levels



Legend:

- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)
- Sample Location
- Location with concentration above criteria
- Area where the estimated concentration is highly uncertain due to limited data.

Notes:

1) Criteria are the SQS, Upper 95th UCL of the Elliott Bay Harbor, Urban and Deep Basin areas and the "Bold Study" data

2) Area colored blue is the estimated area where the sediment concentration exceeds the comparison level.

3) Locations colored red are where the measured concentration exceeds the comparison level.

4) Some data points in Elliott Bay, beyond the extent of the figures are used in the visualization model.

SQS = Sediment Quality Standard
UCL = Upper Confidence Limit

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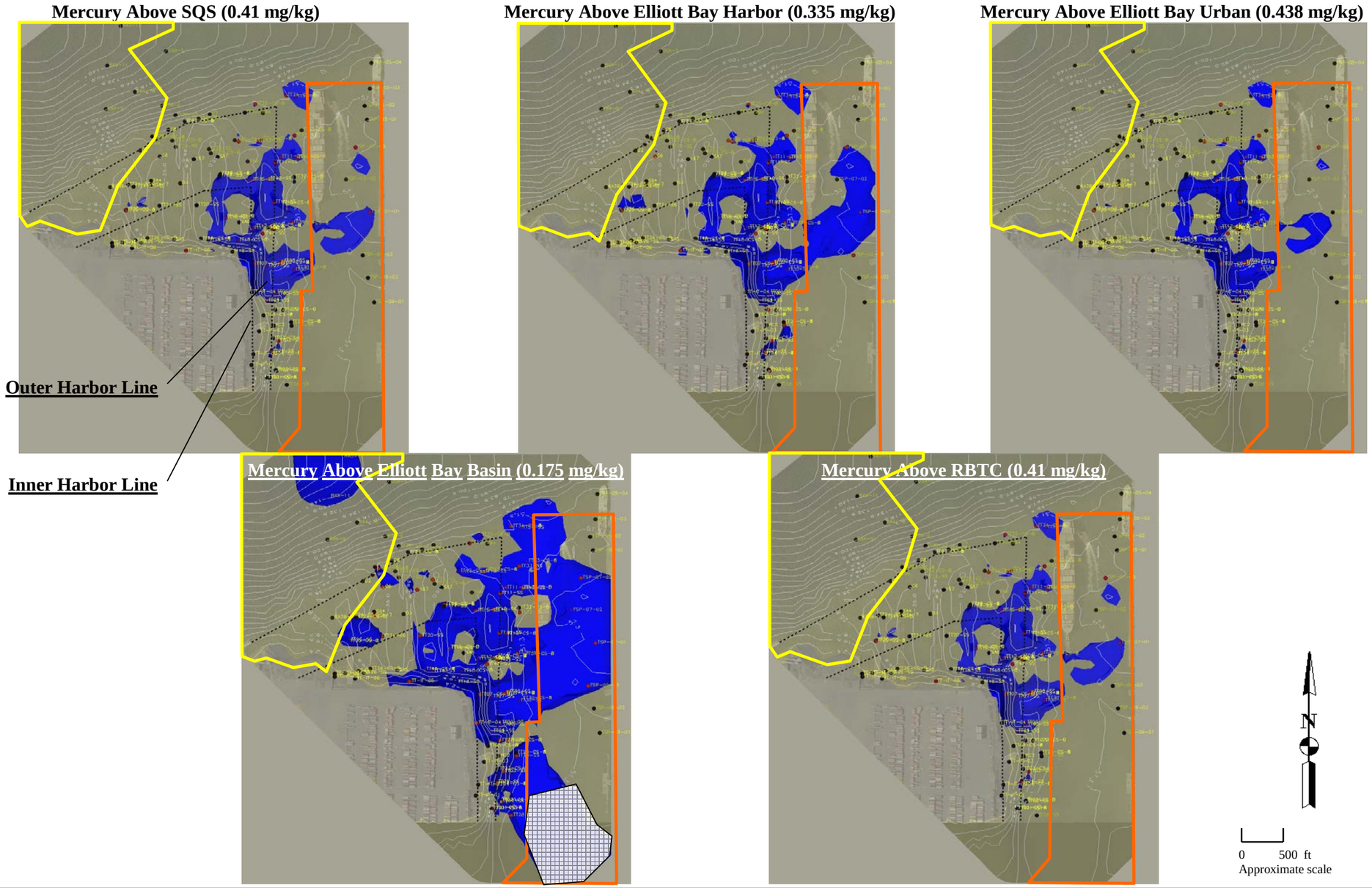
Figure 4-20
Estimated Lead Concentrations in Surface and Subsurface Sediment Above the Screening Levels



Legend:

- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)
- Sample Location
- Location with concentration above criteria
- Area where the estimated concentration is highly uncertain due to limited data.

Notes:

1) Criteria are the SQS, Upper 95th UCL of the Elliott Bay Harbor, Urban and Deep Basin areas and RBTC

2) Area colored blue is the estimated area where the sediment concentration exceeds the comparison level.

3) Locations colored red are where the measured concentration exceeds the comparison level.

4) Some data points in Elliott Bay, beyond the extent of the figures are used in the visualization model.

SQS = Sediment Quality Standard
UCL = Upper Confidence Limit
RBTC = Risk Based Threshold Concentration

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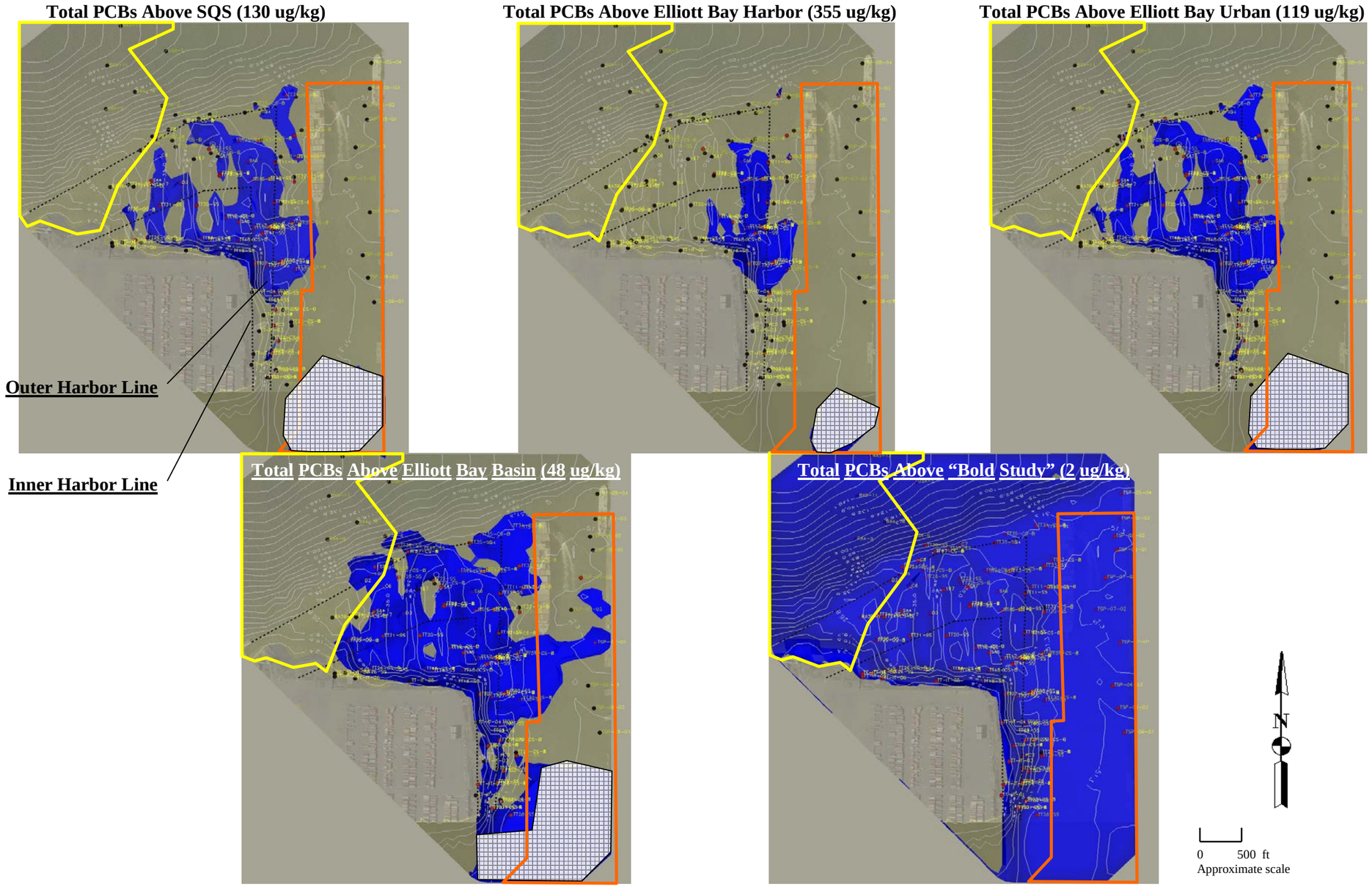
Figure 4-21
Estimated Mercury Concentrations in Surface and Subsurface Sediment Above the Screening Levels



Legend:

- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)
- Sample Location
- Location with concentration above criteria
- Area where the estimated concentration is highly uncertain due to limited data.

Notes:

1) Criteria are the SQS (dry wt equivalent), Upper 95th UCL of the Elliott Bay Harbor, Urban and Deep Basin areas and the "Bold Study" data

2) Area colored blue is the estimated area where the sediment concentration exceeds the comparison level.

3) Locations colored red are where the measured concentration exceeds the comparison level.

4) Some data points in Elliott Bay, beyond the extent of the figures are used in the visualization model.

PCBs = Polychlorinated Biphenyls
SQS = Sediment Quality Standard
UCL = Upper Confidence Limit

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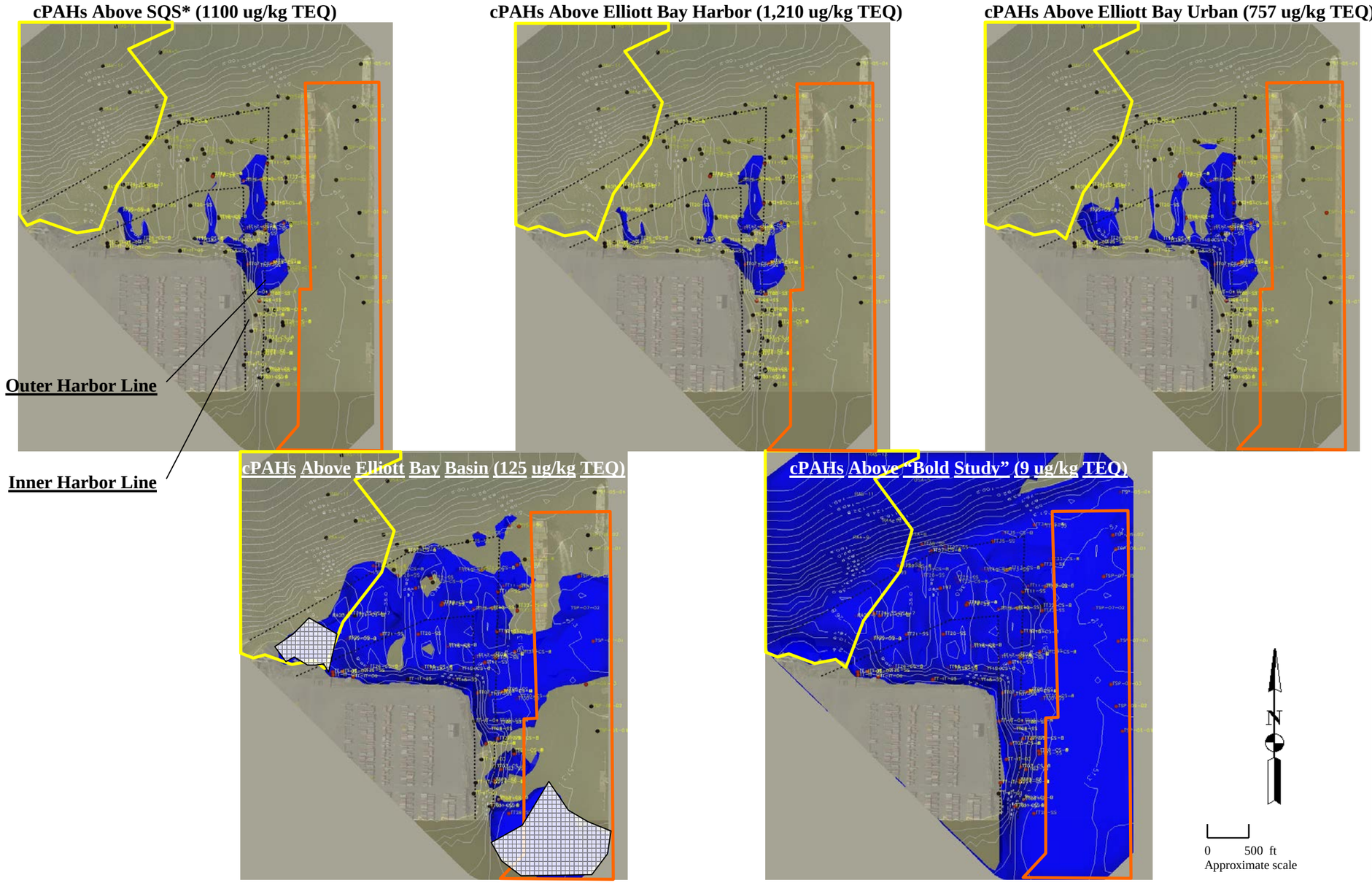
Figure 4-22
Estimated Total PCBs Concentrations in Surface and Subsurface Sediment Above the Screening Levels



Legend:

- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)
- Sample Location
- Location with concentration above criteria
- Area where the estimated concentration is highly uncertain due to limited data.

Notes:

1) Criteria are the SQS* (dry wt equivalent), Upper 95th UCL of the Elliott Bay Harbor, Urban and Deep Basin areas and the "Bold Study" data

2) Area colored blue is the estimated area where the sediment concentration exceeds the comparison level.

3) Locations colored red are where the measured concentration exceeds the comparison level.

4) Some data points in Elliott Bay, beyond the extent of the figures are used in the visualization model.

- SQS (dry wt equivalent) value used is for Benzo(a)pyrene)

SQS = Sediment Quality Standard
TEQ = Toxic Equivalents
UCL = Upper Confidence Limit
cPAHs = Carcinogenic Polycyclic Aromatic Hydrocarbons

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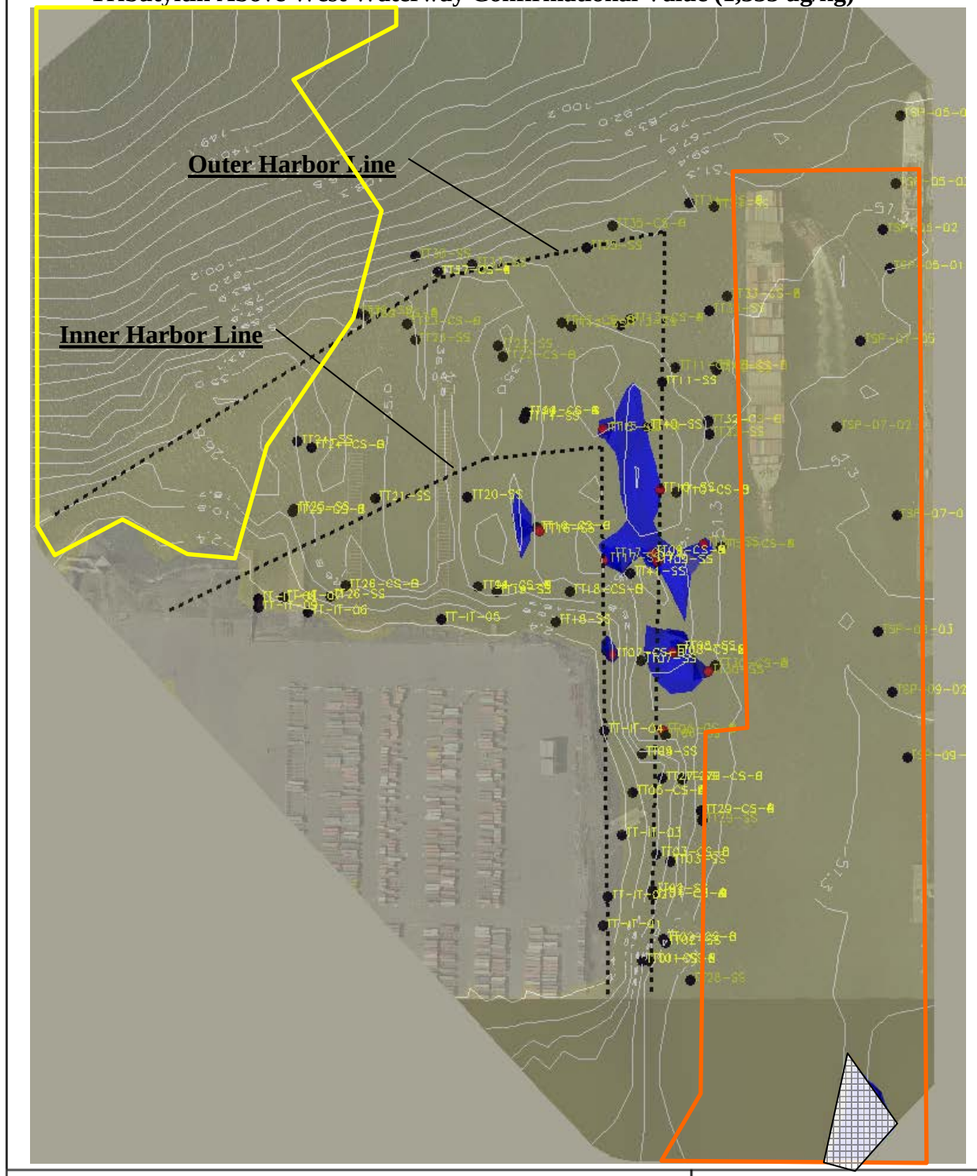
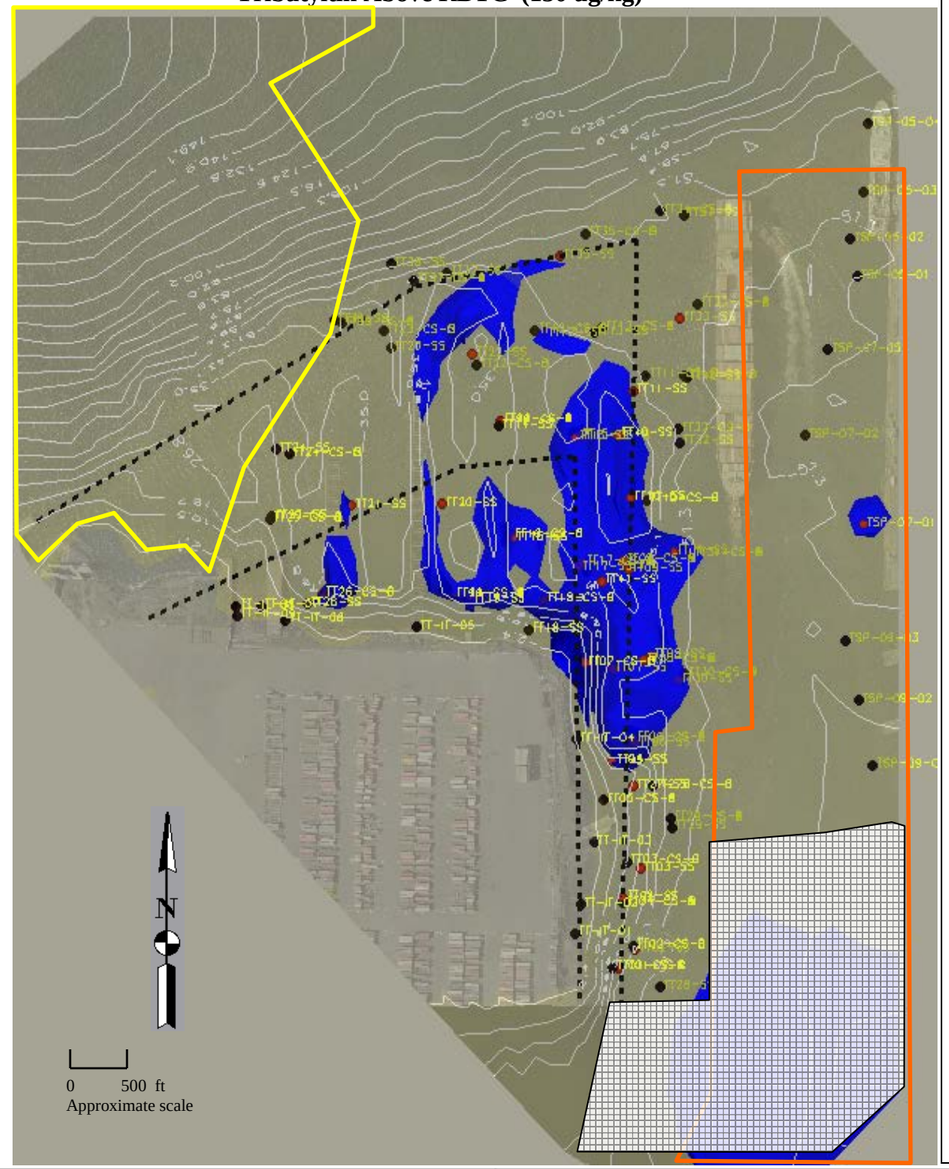
Figure 4-23
Estimated Carcinogenic Polycyclic Aromatic Hydrocarbon Concentrations in Surface and Subsurface Sediment Above the Screening Levels

Tributyltin Above West Waterway Confirmational Value (1,335 ug/kg)



Tributyltin Above RBTC (150 ug/kg)



Legend:

- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)
- Sample Location
- Location with concentration above criteria
- Area where the estimated concentration is highly uncertain due to limited data.

Notes:

1) Criteria are the West Waterway Confirmational Number and the RBTC

2) Area colored blue is the estimated area where the sediment concentration exceeds the comparison level.

3) Locations colored red are where the measured concentration exceeds the comparison level.

4) Some data points in Elliott Bay, beyond the extent of the figures are used in the visualization model.

RBTC = Risk Based Threshold Concentration

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Figure 4-24
Estimated Tributyltin Concentrations in Surface and Subsurface Sediment Above the Screening Levels

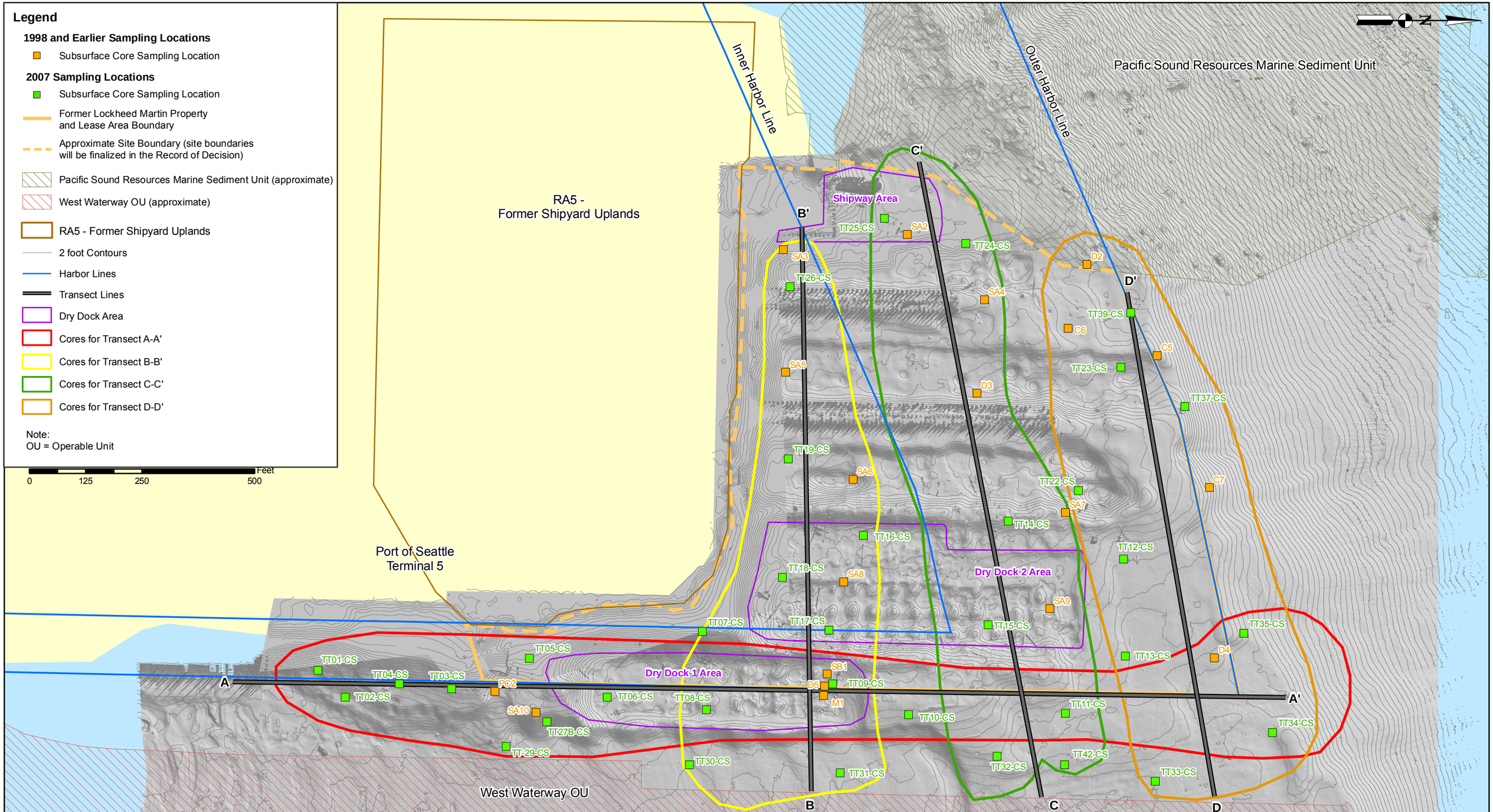

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Figure 4-25 Sediment Core and Transect Locations

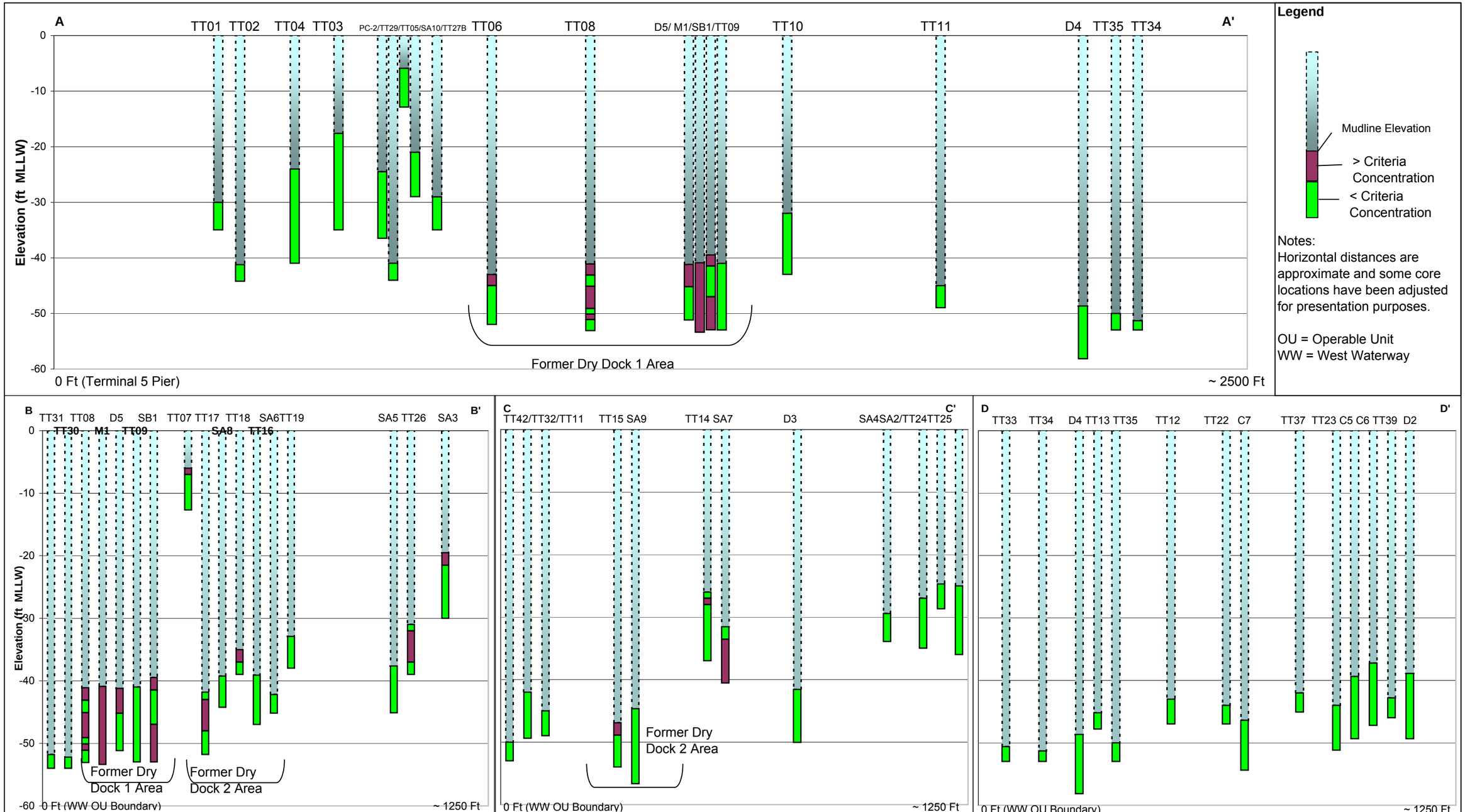

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Figure 4-26
Arsenic Sediment Core Concentrations versus Sediment Quality Standards (57 mg/kg)

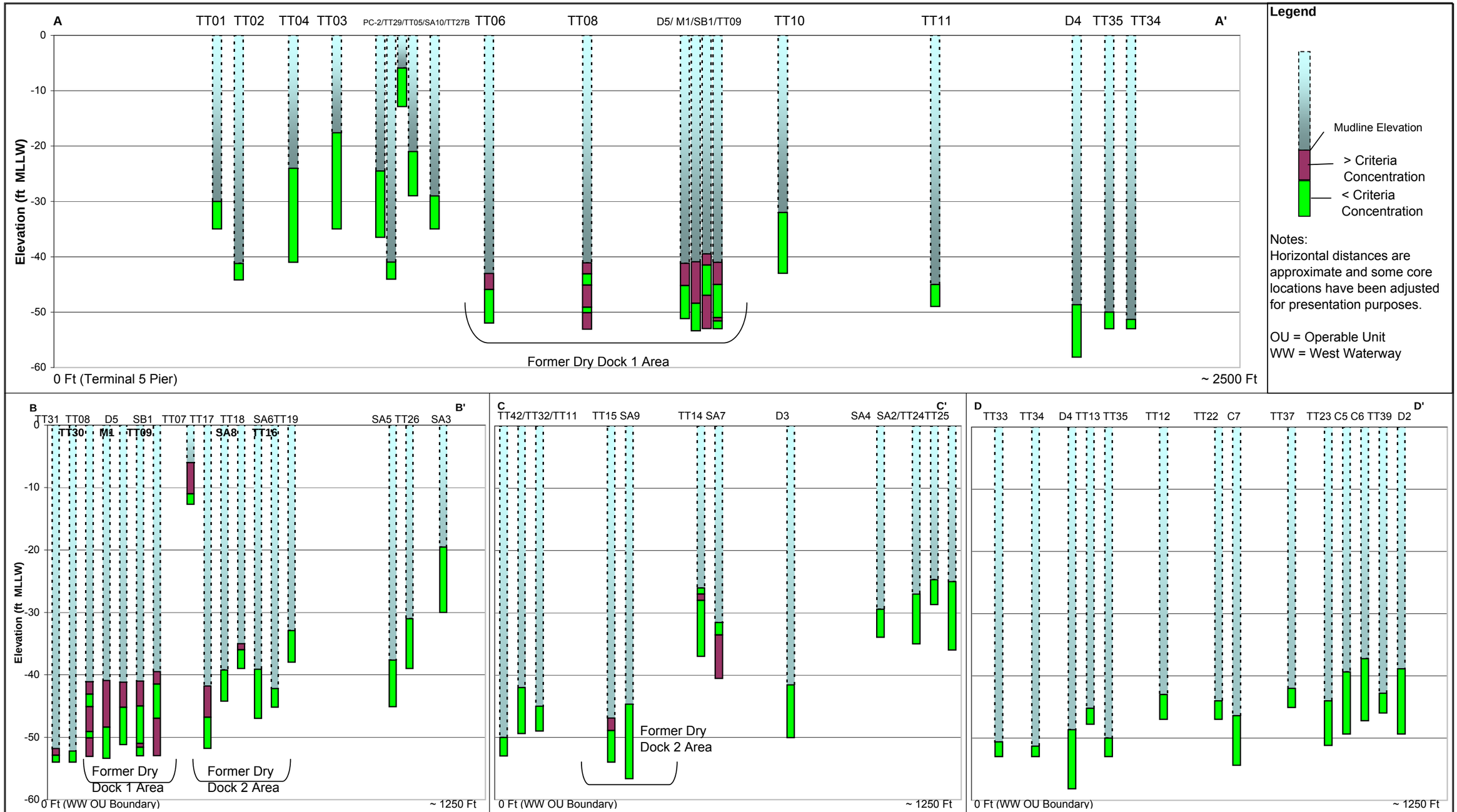

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Figure 4-27
Copper Sediment Core Concentrations versus Sediment Quality Standards (390 mg/kg)

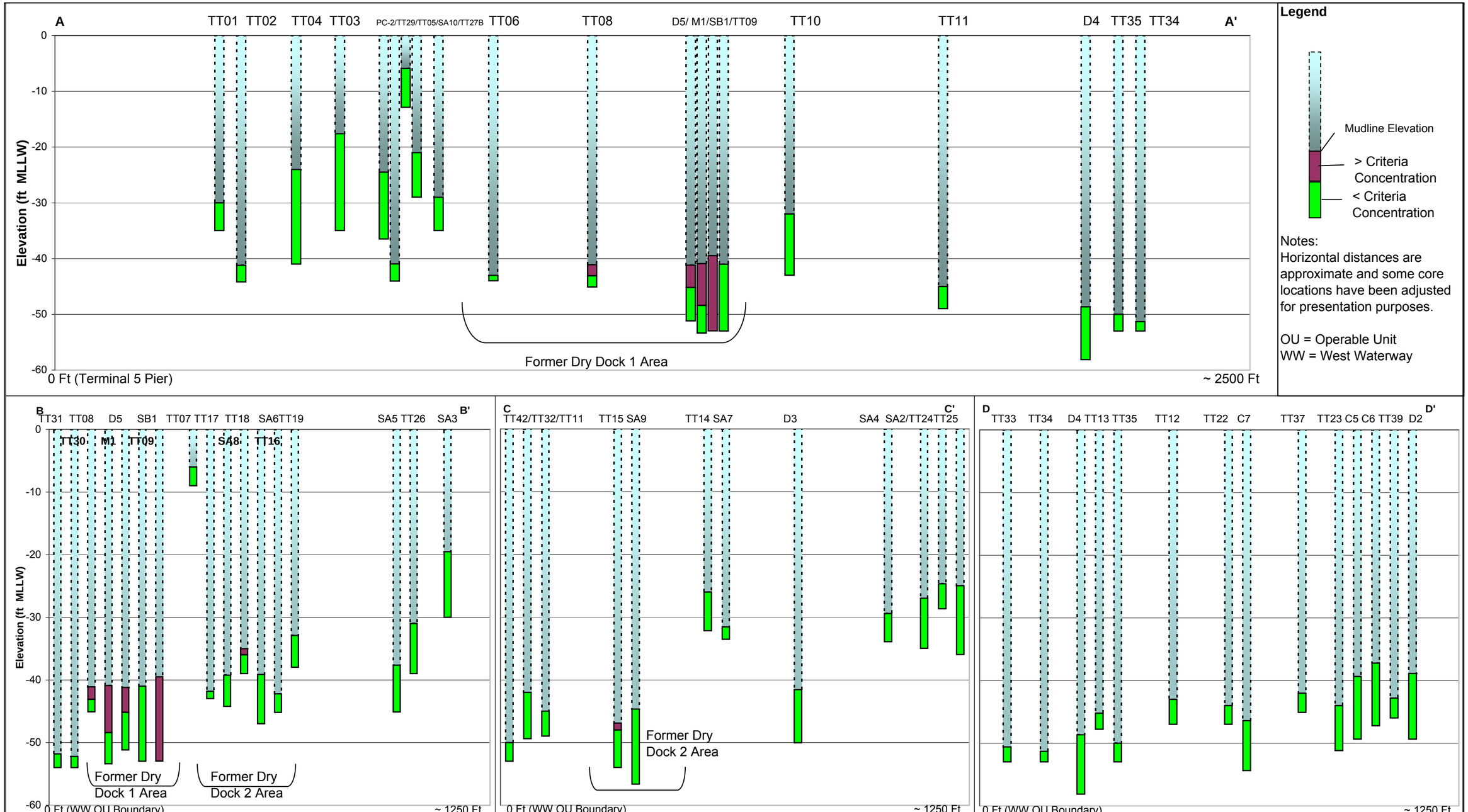

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Figure 4-28
Lead Sediment Core Concentrations versus Sediment Quality Standards (450 mg/kg)

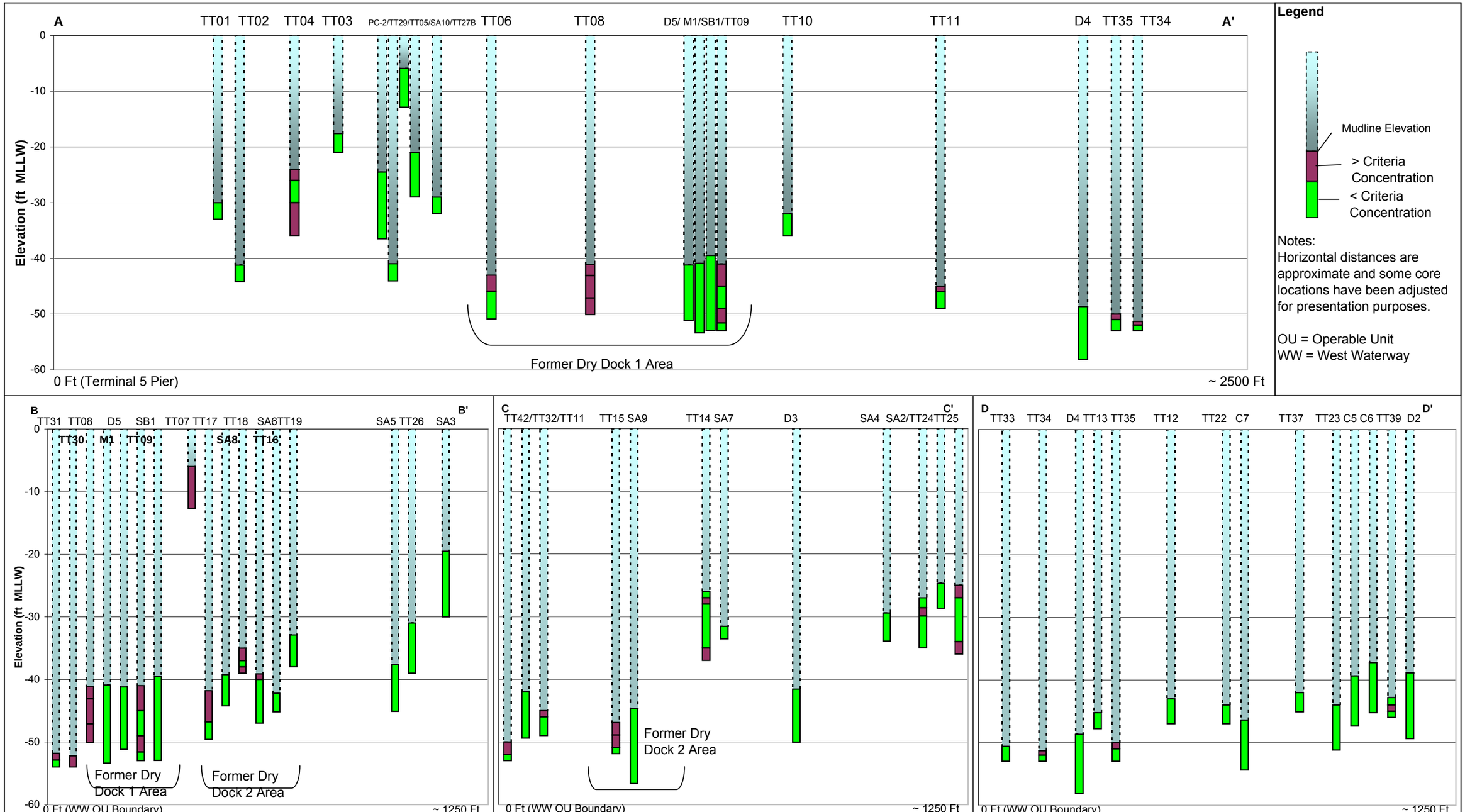

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Figure 4-29
Mercury Sediment Core Concentrations versus Sediment Quality Standards (0.41 mg/kg)

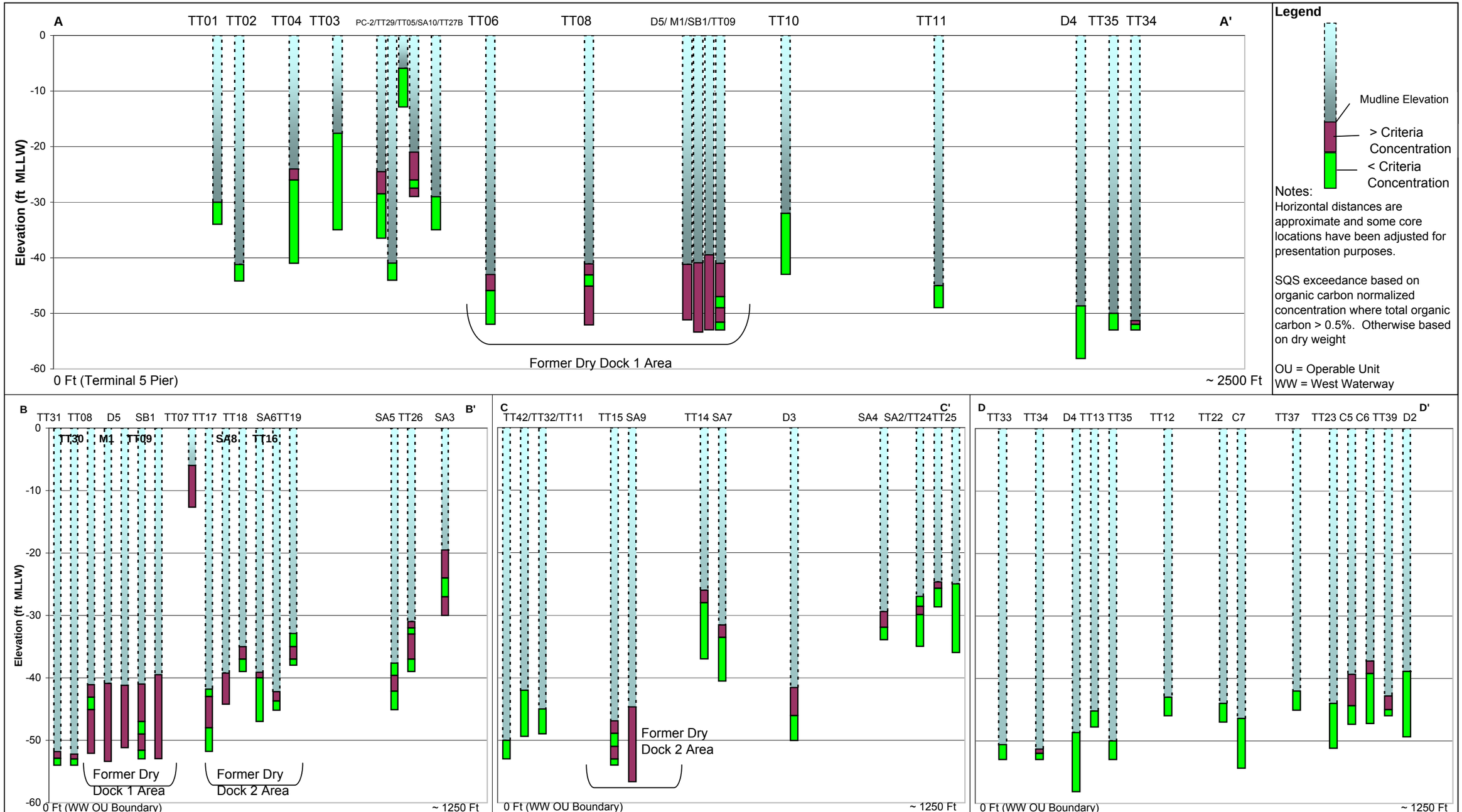

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Figure 4-30
Total PCB Sediment Core Concentrations versus Sediment Quality Standards (12 mg/kg organic carbon)

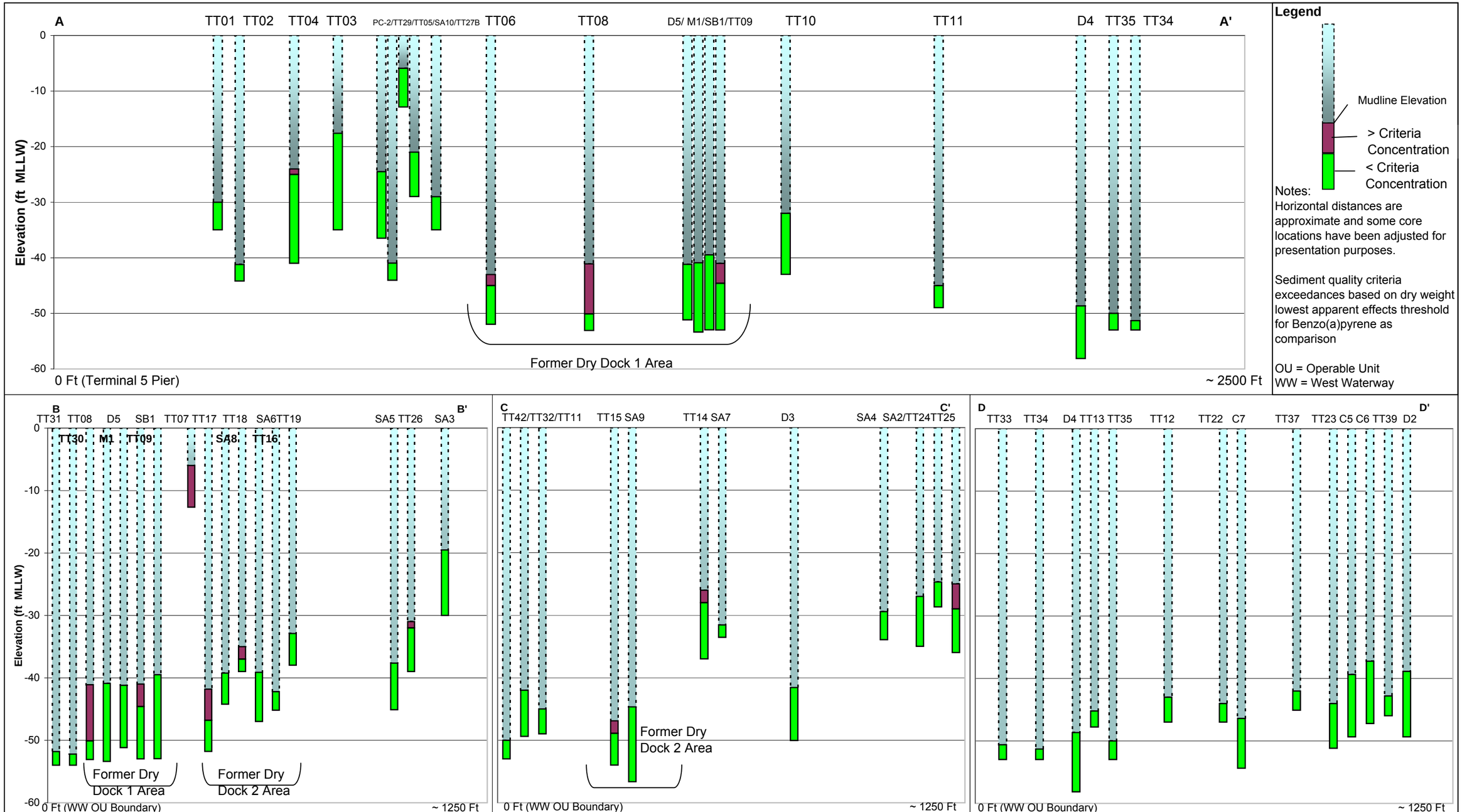

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Figure 4-31
Carcinogenic Polycyclic Aromatic Hydrocarbons Sediment Core Concentrations versus Sediment Quality Standards (1,100 ug/kg)

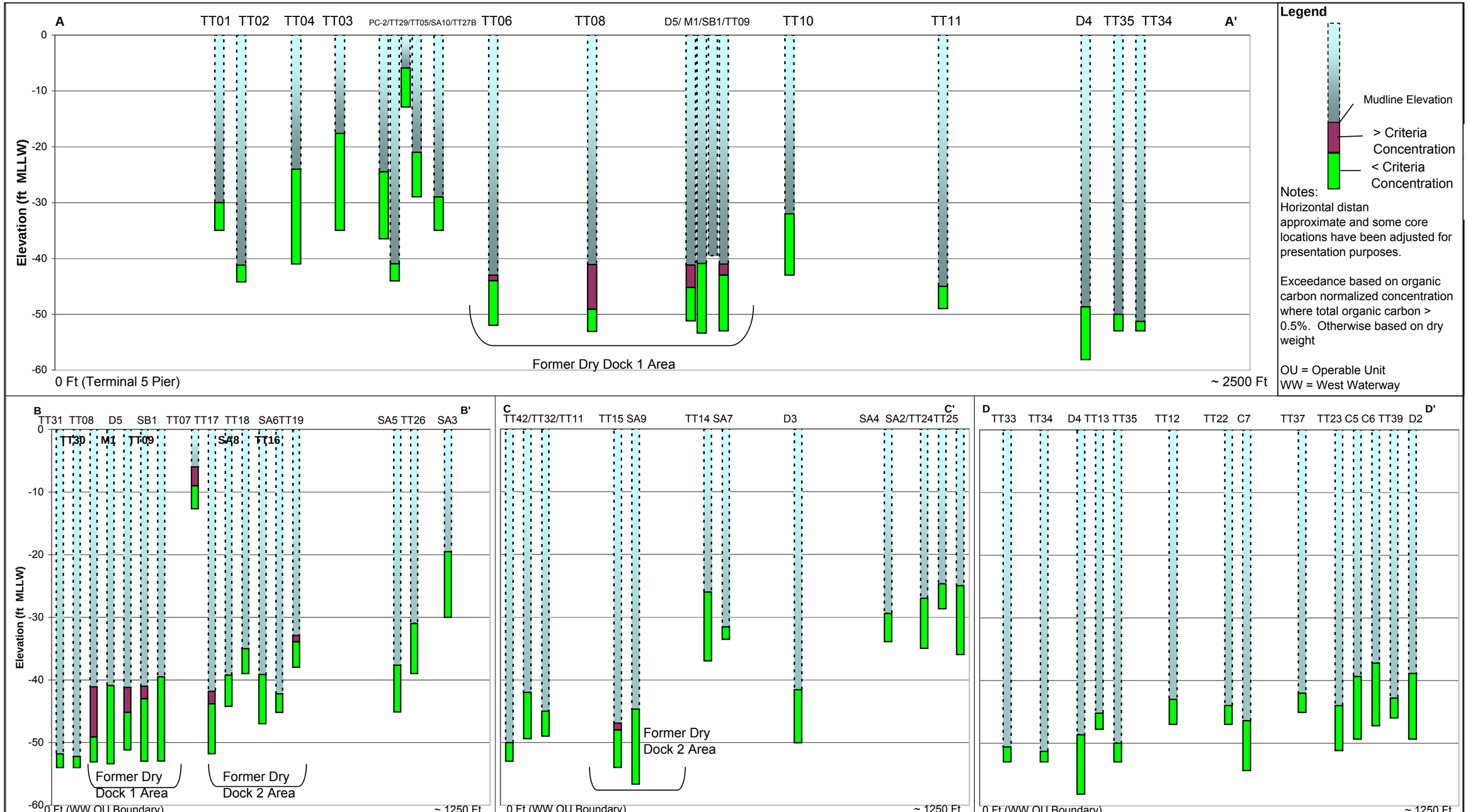

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Figure 4-32
Tributyltin Sediment Core Concentrations versus West Waterway Confirmational Number (76 mg/kg organic carbon)

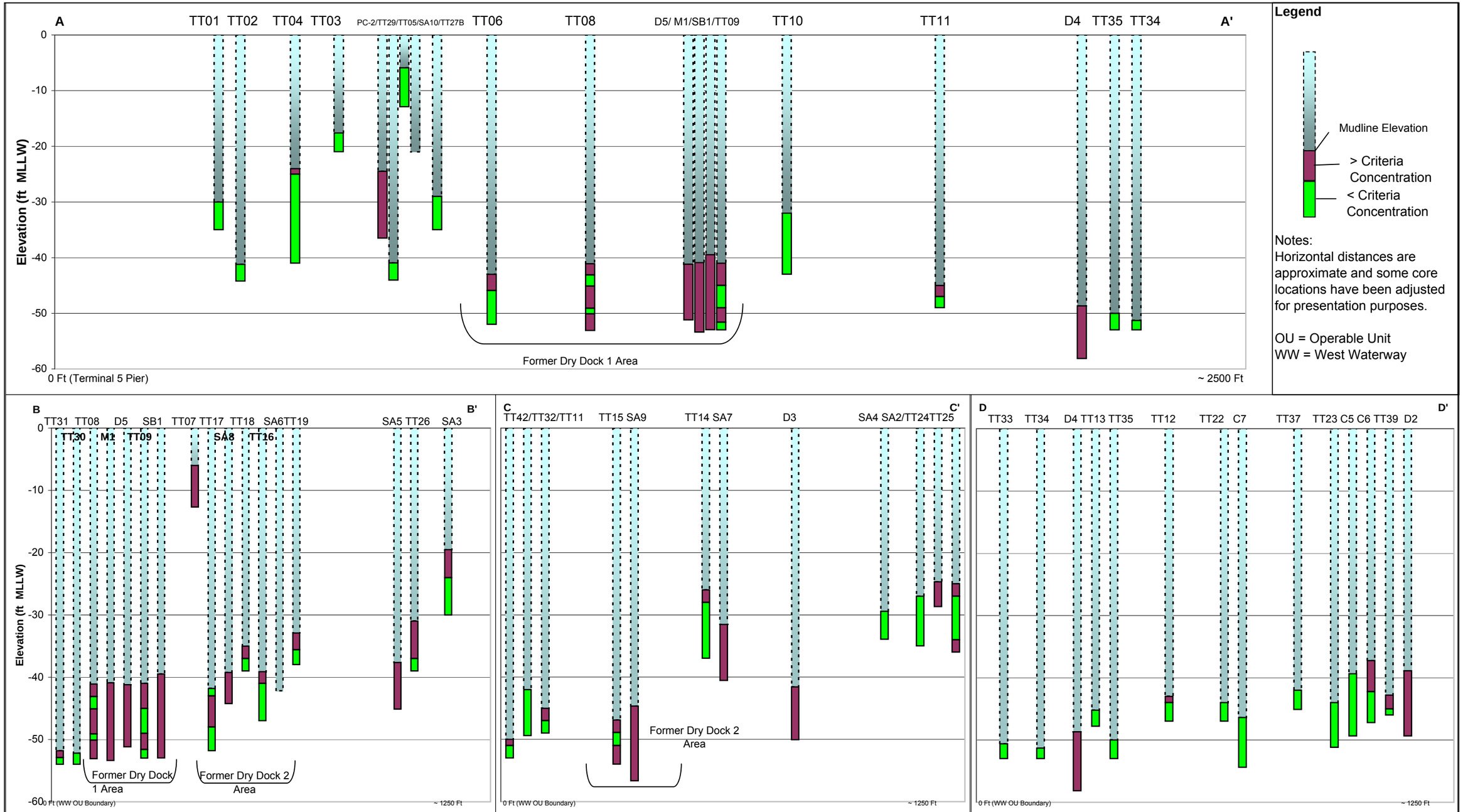

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Figure 4-33
Arsenic Sediment Core Concentrations versus Elliott Bay Urban (8.44 mg/kg)

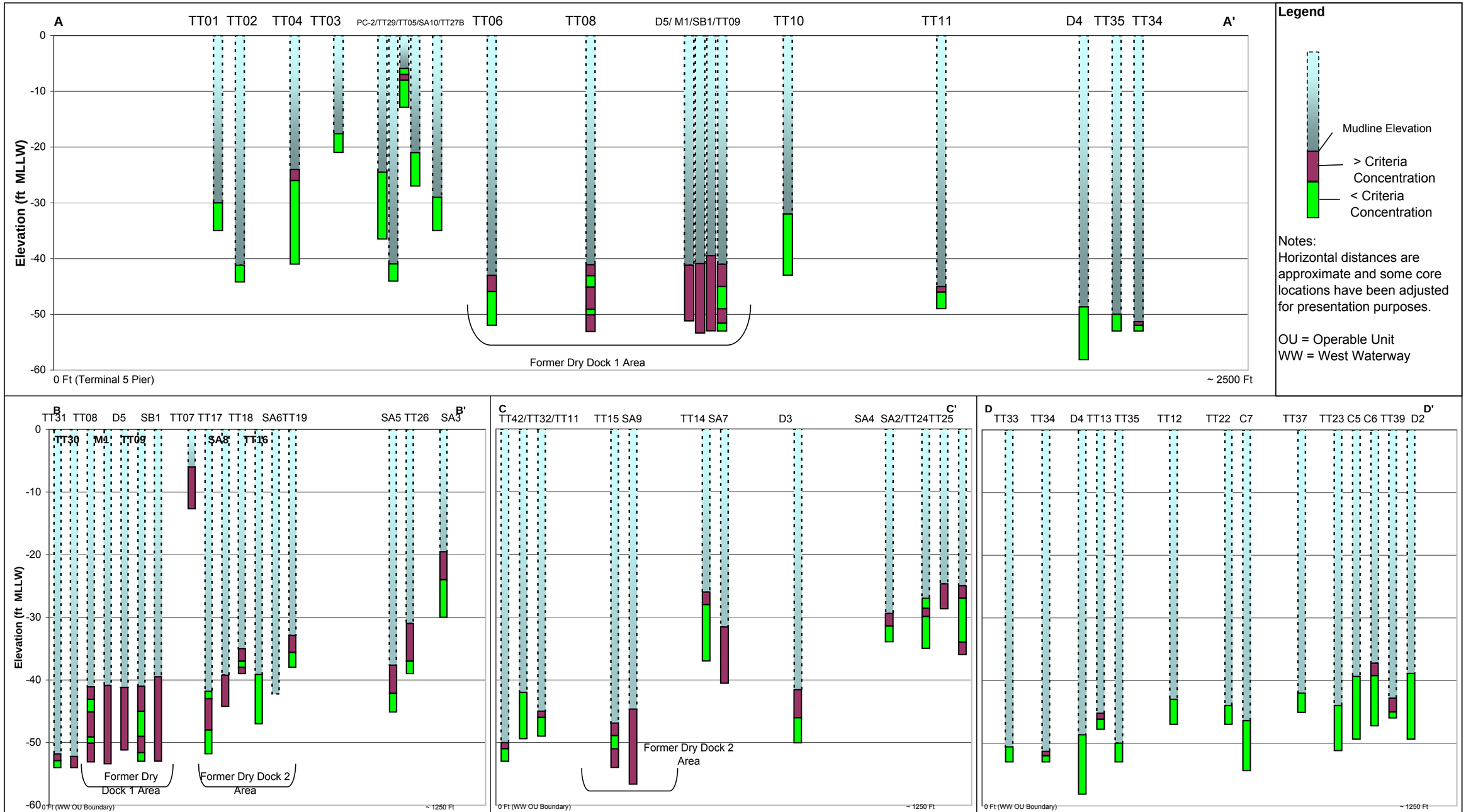

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Figure 4-34
Copper Sediment Core Concentrations versus Elliott Bay Urban (48.9 mg/kg)

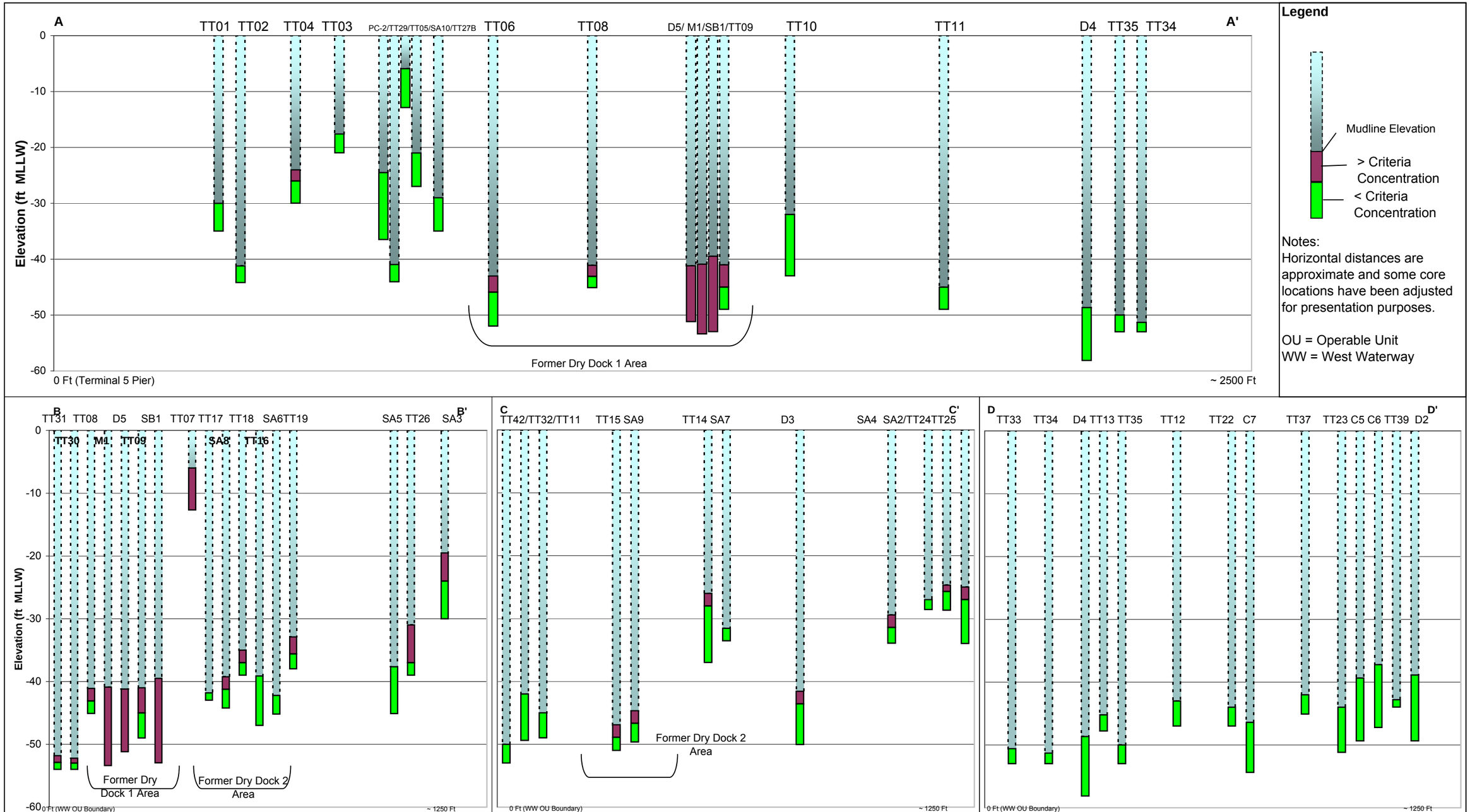

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Figure 4-35
Lead Sediment Core Concentrations versus Elliott Bay Urban (47 mg/kg)

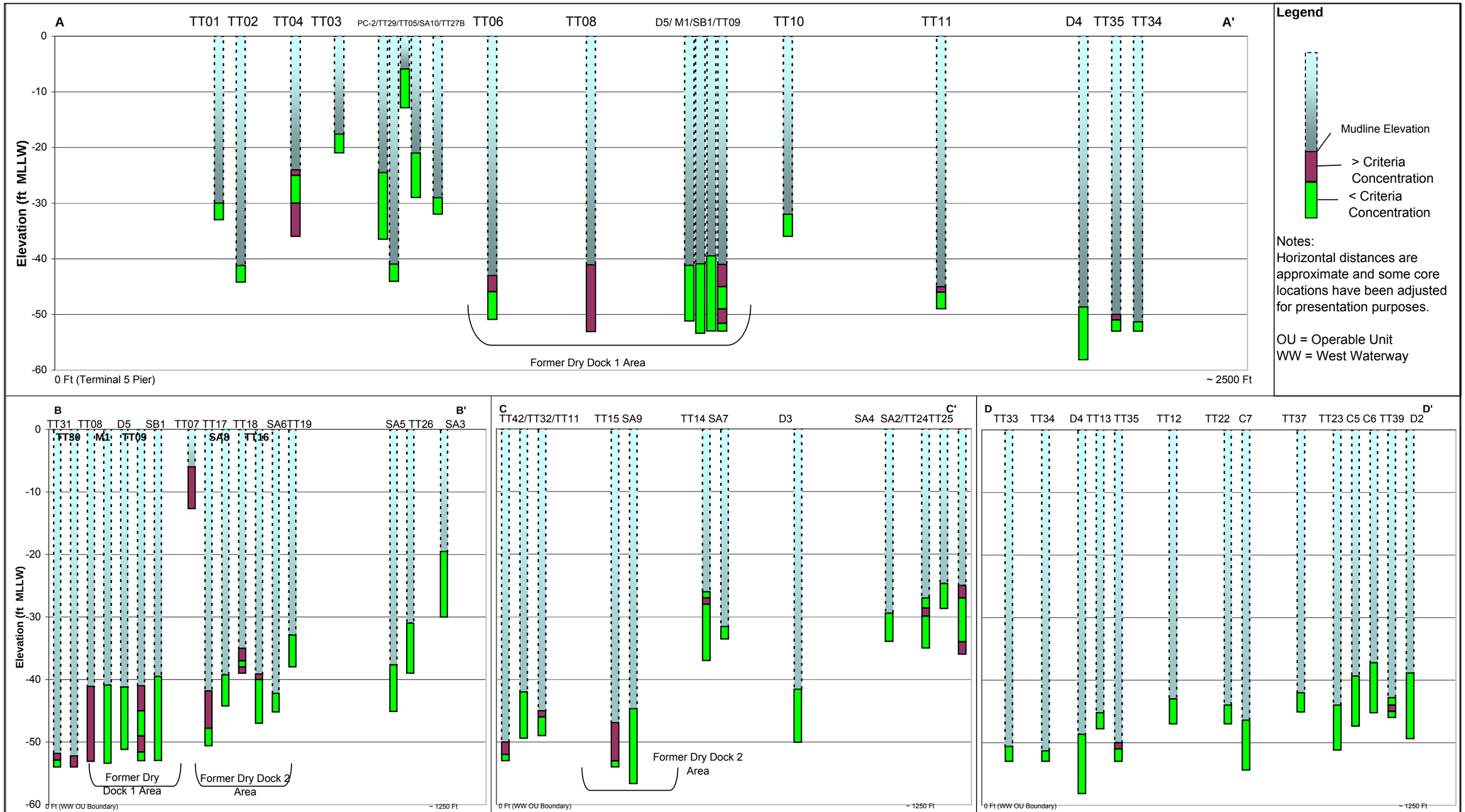

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Figure 4-36
Mercury Sediment Core Concentrations versus Elliott Bay Urban (0.438 mg/kg)

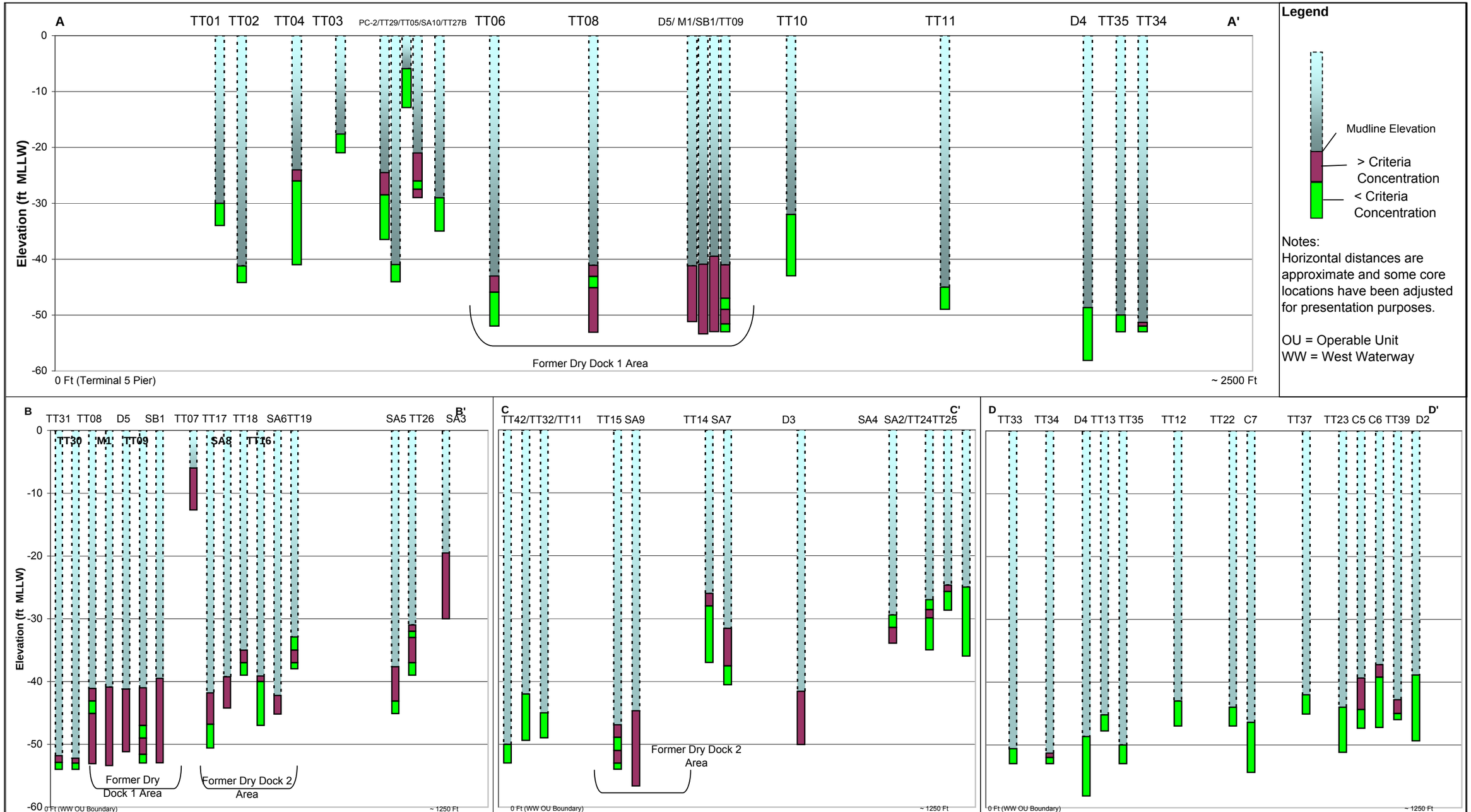

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Figure 4-37
Total PCBs Sediment Core Concentrations versus Elliott Bay Urban (119 ug/kg)

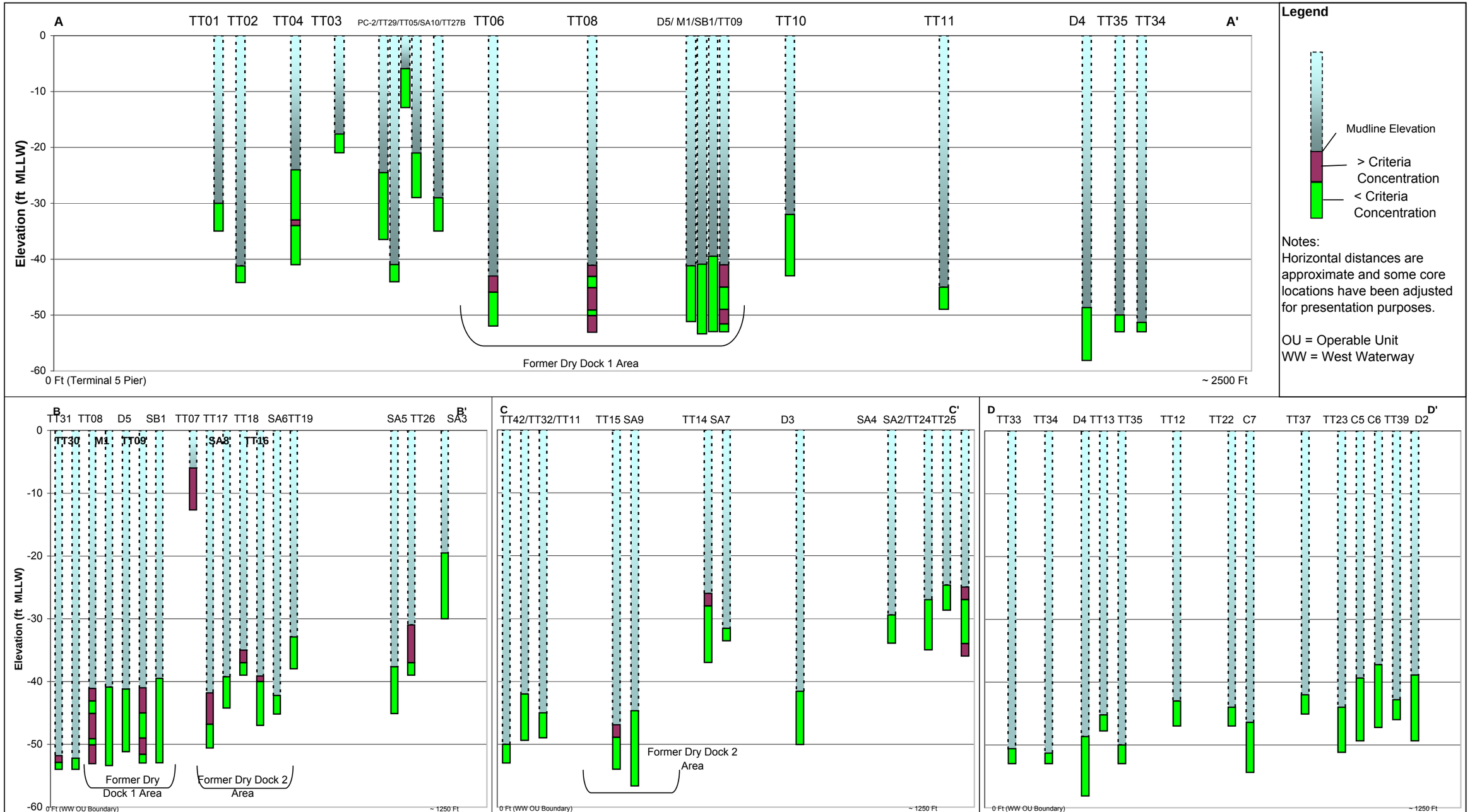

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Figure 4-38
Carcinogenic Polycyclic Aromatic Hydrocarbons Sediment Core Concentrations versus Elliott Bay Urban (757 ug/kg)

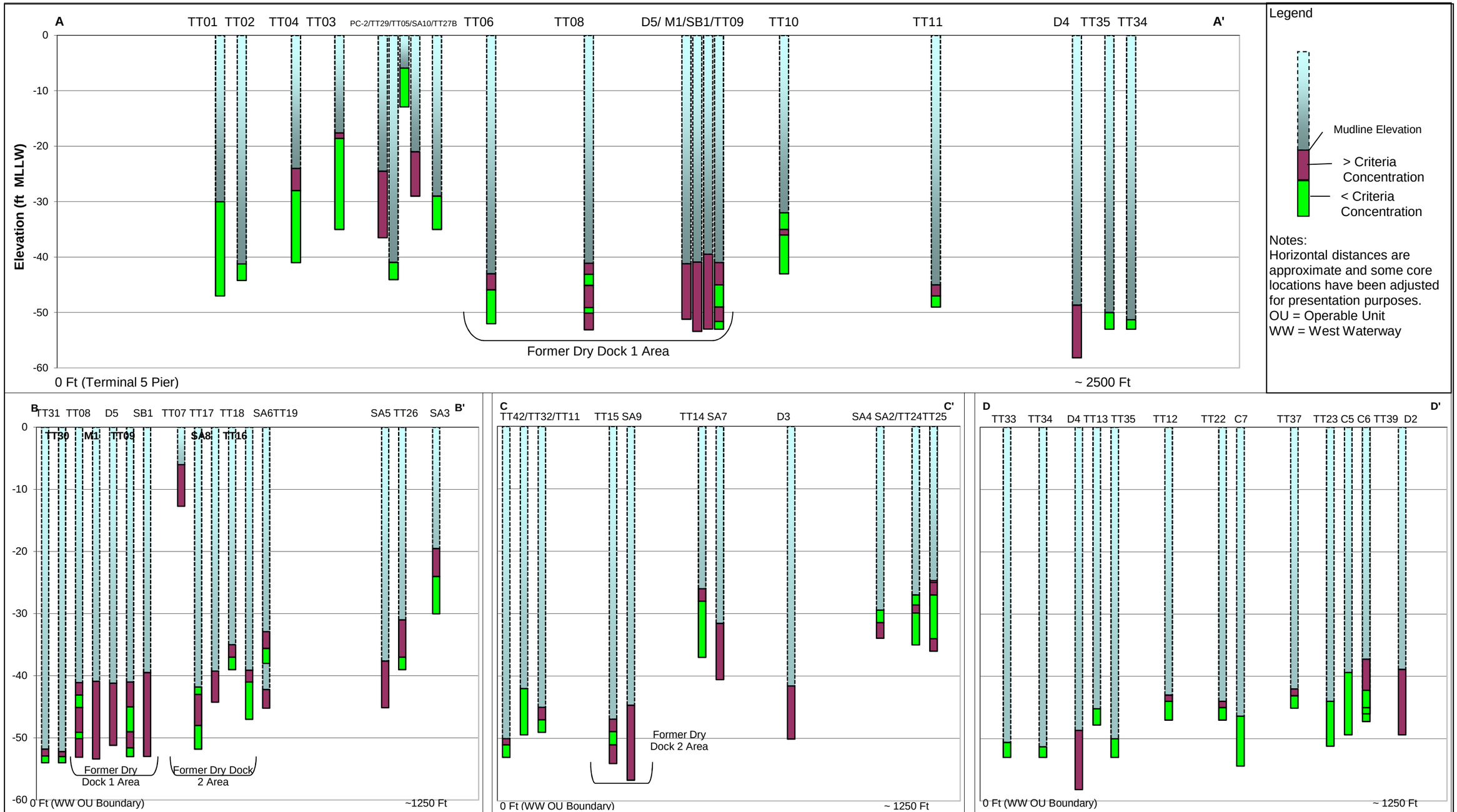

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Figure 4-39
Arsenic Sediment Core Concentrations vs Puget Sound - Bold Study (7 mg/kg)

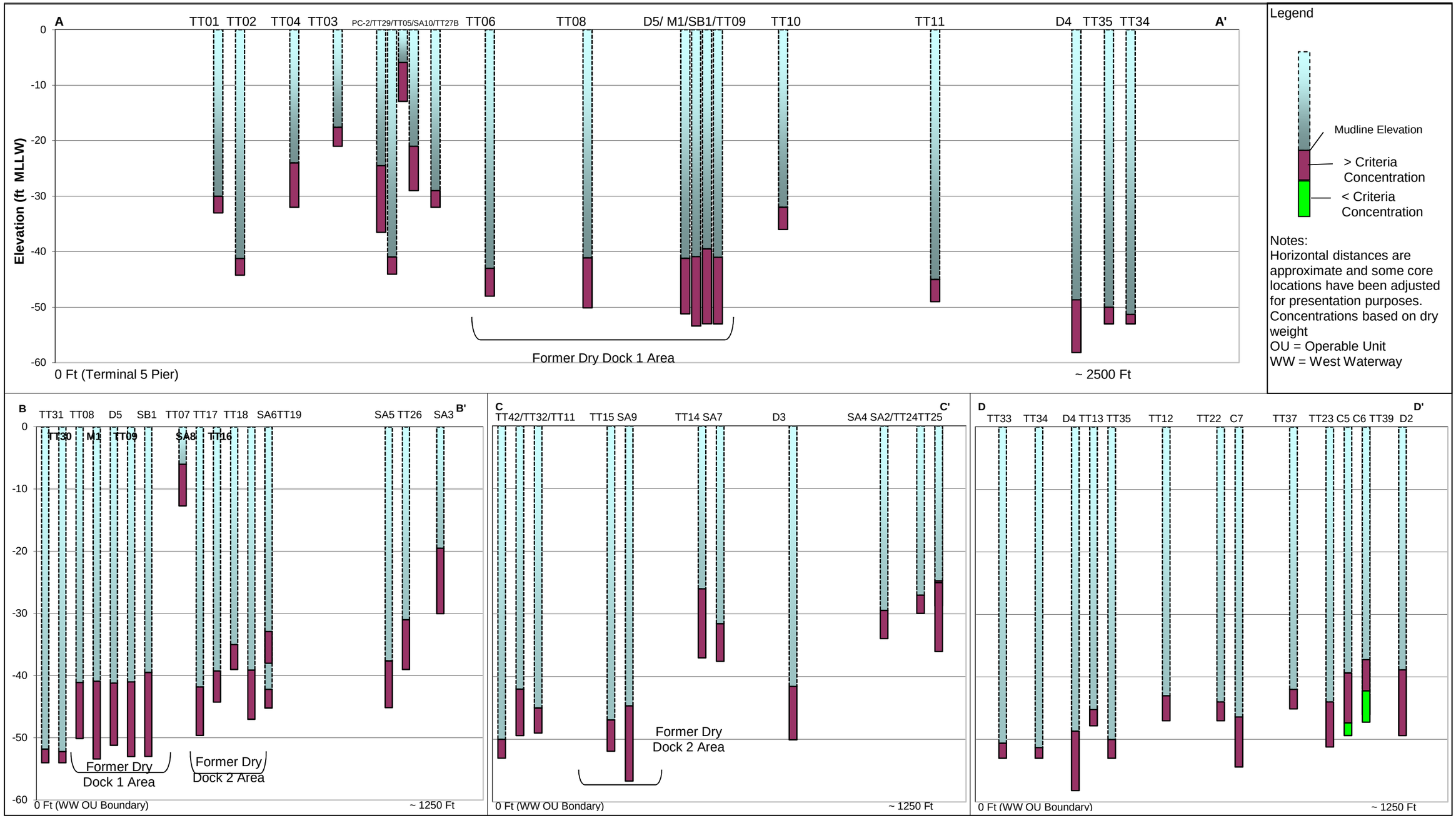

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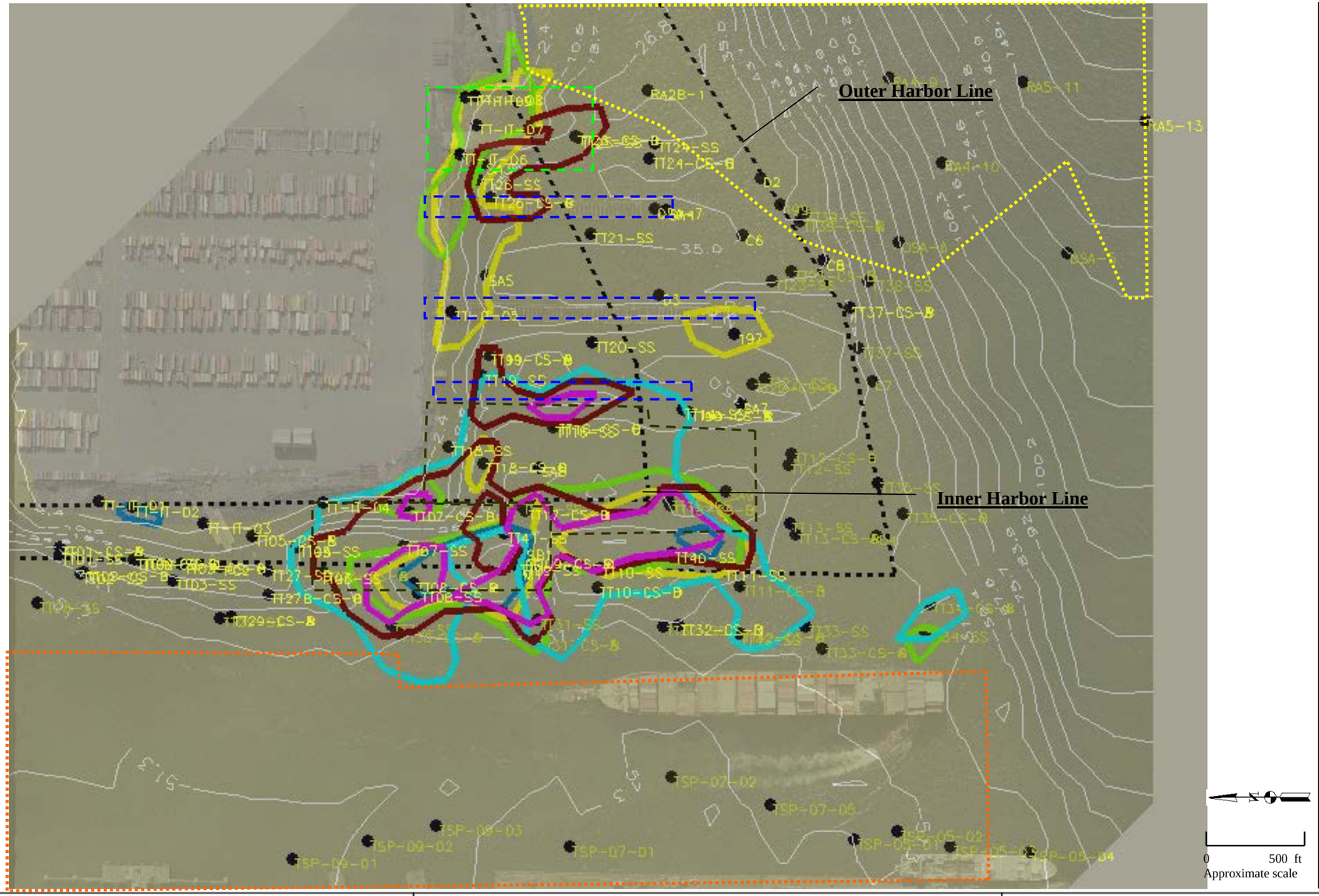
Figure 4-40
Total PCB Sediment Core Concentrations vs Puget Sound - Bold Study (2 ug/kg)



Notes/Legend:

- cPAHs
- Tributyltin
- Arsenic
- Copper
- Lead
- Mercury
- Sample Locations
- Former Dry Docks
- Piers
- Shipway
- West Waterway OU Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)

For Tributyltin the West Waterway Confirmational Number is used

For cPAHs the SQS (dry weight equivalent) value for Benzo(a)pyrene is used

cPAHs = carcinogenic polycyclic aromatic hydrocarbons

OU = Operable Unit

PCBs = polychlorinated biphenyls

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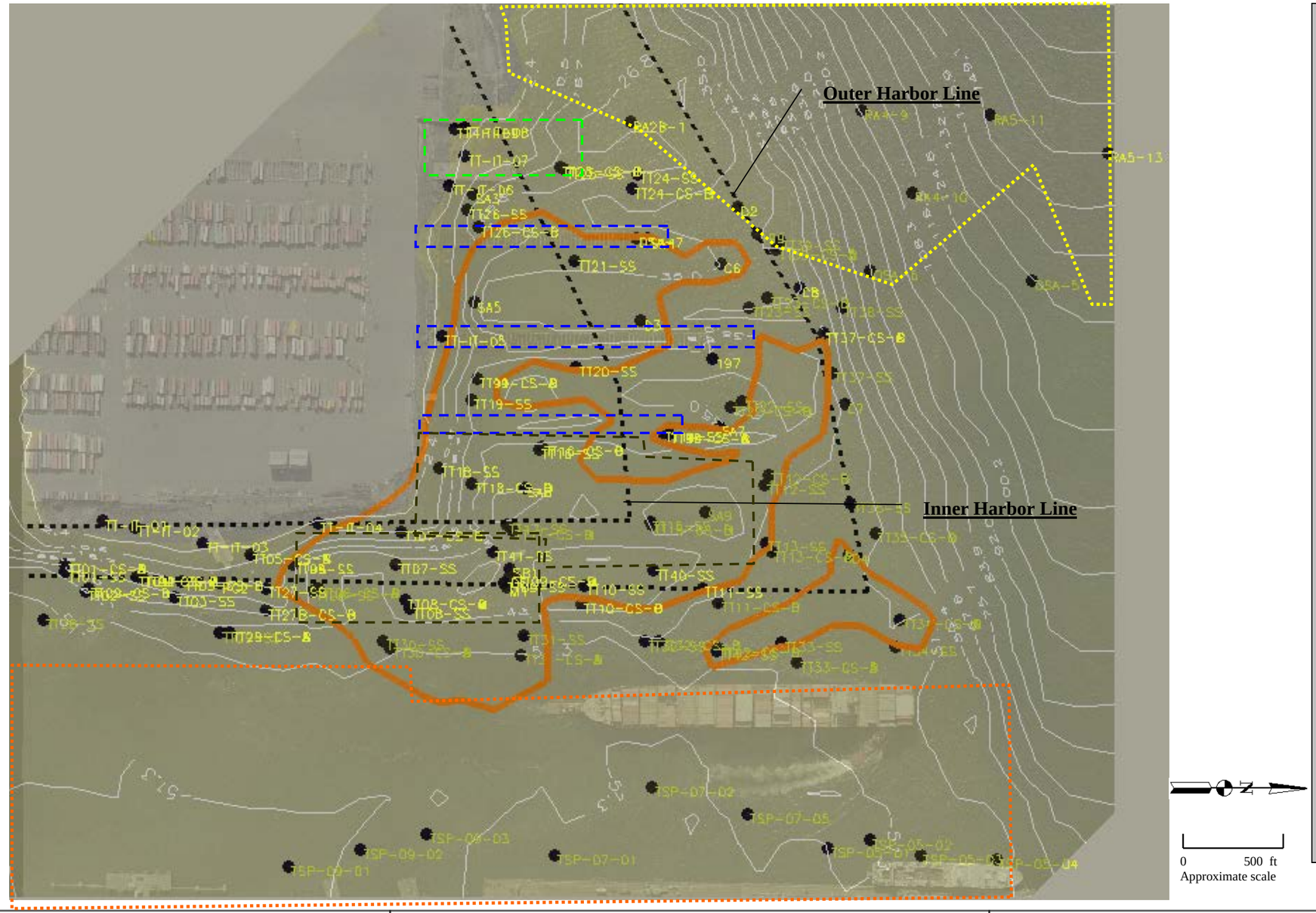
Figure 4-41

Extent of Surface and Subsurface Contamination for Risk Driver Contaminants of Concern (excluding PCBs) Above the Sediment Quality Standards in the Lockheed West Study Area



Notes/Legend:

- Total PCBs
- Sample Locations
- Former Dry Docks
- Piers
- Shipway
- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)

For PCBs the Sediment Quality Standard (dry weight equivalent) value is used

PCBs = polychlorinated biphenyls

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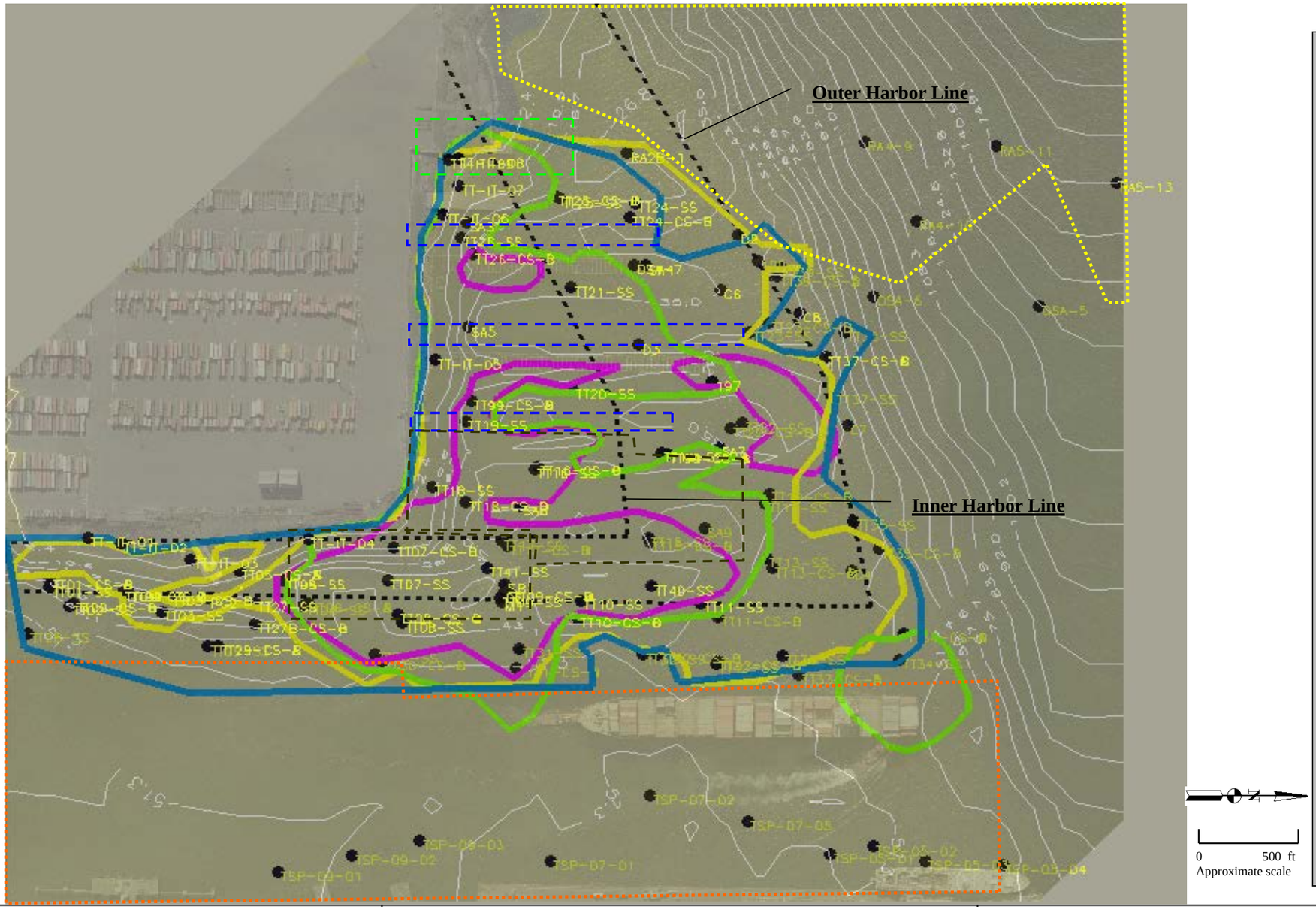
Figure 4-42
Extent of Surface and Subsurface Contamination for PCBs Above the Sediment Quality Standard in the Lockheed West Study Area



Notes/Legend:

- Tributyltin
- Arsenic
- Copper
- Lead
- Sample Locations
- Former Dry Docks
- Piers
- Shipway
- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit Boundary (approximate)

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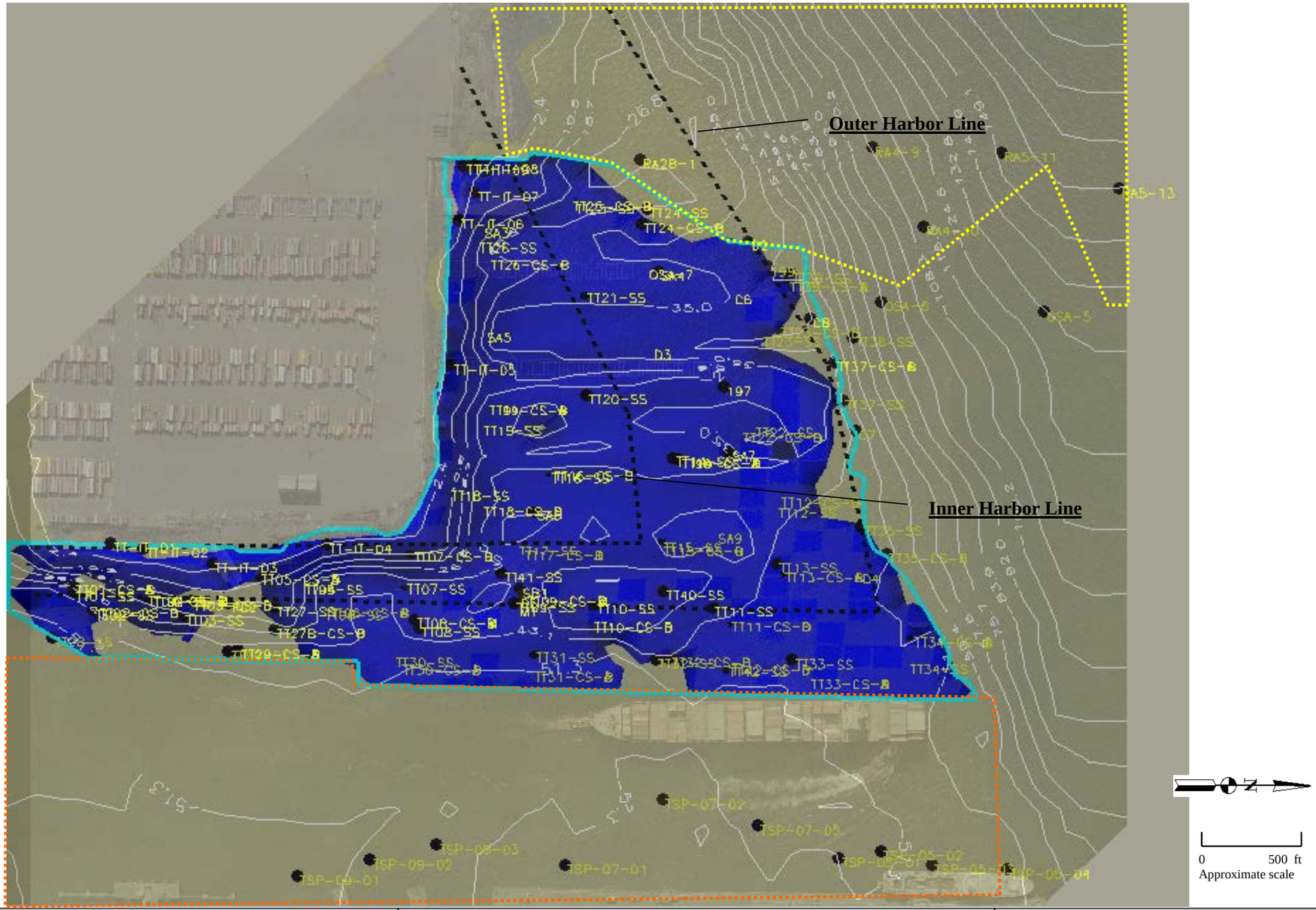
Figure 4-43
Extent of Surface and Subsurface Contamination for Arsenic, Copper, Lead and Tributyltin Above the "Bold Study" or Risk-Based Threshold Concentration in the Lockheed West Study Area



Notes/Legend:

- West Waterway Operable Unit Boundary (approximate)
- Pacific Sound Resources Marine Sediment Unit (approximate)
- Study Area Boundary
- Sample Locations

Area colored blue is the estimated extent of sediment contamination in the Study Area.

Study Area Boundary encompasses the extent of sediment SQS exceedances for PCBs and PAHs

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Figure 4-44 Horizontal Extent of Surface and Subsurface Sediment Contamination for the Lockheed West Study Area

SECTION 5

Potential Contamination Sources, Pathways, and Source Control

This section summarizes the major conclusions for the source control evaluation. The overall purpose of the source control evaluation is to identify and assess potential sources of recontamination to the Lockheed West Site. The general scope of the remedy recontamination evaluation for potential sources is defined in the *RI/FS Work Plan*. The overall objectives of the source control work effort are to:

- Identify potential sources and assess the potential pathways and the potential for recontamination of the Lockheed West Site following its remediation;
- Evaluate whether the re-suspension, transport, and deposition of bottom sediments in the adjacent Elliott Bay and West Waterway are a potential ongoing source of chemical contamination that could result in recontamination of the Lockheed West Site after remediation;
- Qualitatively compare available source information to existing sediment quality data;
- Identify data gaps that should be addressed so that the status of source control at the Lockheed West Site can be confirmed; and
- Make recommendations regarding the need for further investigation or control of identified potential sources.

The source control evaluation is presented in two main reports: the *Source Control Information and Data Gap Report* and the *Source Control Evaluation Report*. Both reports have been approved as final by EPA. The two reports work together to cover the topic of source control. The first report summarizes readily available information regarding potential sources and pathways and identifies data needs. The second report includes additional data and information collected to supplement the first report and provides an evaluation of the sources and pathways that were identified as most likely of concern from a remedy recontamination standpoint. Figure 5-1 illustrates how the source control evaluation fits in with the RI/FS process for this project. As

shown in Figure 5-1, the source control reports will be used to identify likely sources and pathways of concern and ongoing monitoring needs. The identified source control issues relating to remedy selection and conceptual design are evaluated in the FS portion of this report. Source control considerations will continue to be addressed through the entire remedial design and implementation process.

An understanding of potential sources of recontamination is important to evaluate whether the remedy will likely remain protective and to determine parameters on which to measure long-term performance. Figure 2-10 shows a conceptual diagram of the types of sources that were evaluated in support of the source control evaluation process. The following potential sources were evaluated: overwater uses and spills, wastewater discharges, combined sewer overflows, stormwater discharges, upland contaminated sites, sediment transport, and atmospheric deposition.

The major findings of the source control evaluation reports are presented in this section. For detailed supporting documentation and evaluation, refer to the *Source Control Information and Data Gap Report* and the *Source Control Evaluation Report*. Due to the proximity of the Lockheed West Site to adjacent cleanup sites as well as regulated discharges, implementation of source control activities and long-term monitoring will require coordination and likely participation of the following parties:

- Lockheed Martin is responsible for implementing the RI/FS for the Lockheed West Site.
- The EPA is the lead regulatory agency for the Lockheed West Site cleanup. In addition, the EPA (with support of the U.S. Army Corps of Engineers) is currently responsible for the long-term monitoring of the upland and sediment OU remedies for the neighboring PSR site; EPA is also the lead regulatory agency responsible for the cleanup there. More generally, the EPA has regulatory authority for surface water programs including combined sewer overflows. The EPA will coordinate community involvement and distribution of information to stakeholders including tribal natural resource trustees. Specific parties (e.g., Tribes) that need to be involved in the coordination of long-term monitoring will be identified and notified.
- The Port is the current landowner for Terminal 5 and a portion (about 7 acres of aquatic land) of the Lockheed West Site. Under the Port Management Agreement (22-080031), the Port also assumed management authority for harbor leases along the eastern portion of the Lockheed West Site. As part of the SWHP, the Port is responsible for groundwater

monitoring associated with the former shipyard uplands adjacent to the Lockheed West Site (Remediation Area [RA] 5) as well as other nearby areas. At Terminal 5, the Port and their tenants are responsible for compliance with existing stormwater regulations including obtaining necessary National Pollutant Discharge Elimination System (NPDES) general industrial stormwater permits and meeting the permit requirements.

- Ecology is the lead regulatory agency responsible with the administration of the SWHP. In addition, Ecology is the lead agency for implementation of NPDES permit requirements and other surface water protection programs. Ecology has also been assigned to act as the State's lead natural resource trustee.
- The Washington State Department of Natural Resources manages the state-owned aquatic land that comprises a significant portion of the Lockheed West Site. Much of this aquatic land was formerly leased to Lockheed Martin by DNR. The Port later assumed these harbor leases. In a December 5, 1996, letter to DNR, the Port deleted the non-filled portion of the harbor area leases in the northern portion of the Lockheed West Site (22-002564, 22-002119, and 22-001982) from Port management so they revert back to DNR to manage.
- The City of Seattle is responsible for implementation of NPDES permit requirements for City-owned storm drainage systems and combined sewer overflows (CSOs). Based on the *Source Control Information and Data Gap Report* findings, it appears that City-owned CSOs do not occur in the immediate Site vicinity. Based on conversations with representatives of the City of Seattle and Port, there is some uncertainty regarding the ownership and easement status of the SW Florida Street Outfall and associated drainage. However, easement information provided by DNR indicates that the City of Seattle was granted a right-of-way for this feature in 1964 (DNR, 1964).
- King County is responsible for implementation of NPDES permit requirements for county-owned storm drainage systems and CSOs. Based on the *Source Control Information and Data Gap Report* findings, it appears that County-owned drainage systems and CSOs do not occur in the immediate Site vicinity.

5.1 SUMMARY OF EVALUATION FOR POTENTIAL SOURCES TYPES

The Lockheed West Site is situated at the mouth of the West Waterway, which is an actively maintained waterway used for navigation, commercial, and industrial purposes. The Lower Duwamish Waterway discharges to Elliott Bay through the West Waterway. As would be expected, there are several potential sources in the Site vicinity. Figure 3-1 shows major environmental cleanup sites and drainage features in the Site vicinity. All of the features

included in Figure 3-1 were evaluated in detail in the source control reports and are briefly summarized in this section for clarity. The scope of the source control evaluation with respect to the various source area categories is briefly explained in the following sections.

5.1.1 Overwater Uses and Spills

Current uses and planned future uses of Terminal 5 and the Lockheed West Site were summarized as part of the source control evaluations. A search of federal, state, and local spill reporting databases was conducted to assess the recent history of reported spills within the West Waterway. These databases included the federal Emergency Response Notification System maintained by the U.S. Coast Guard and the spills database maintained by the Ecology Spill Prevention, Preparedness, and Response Program. In response to project team comments, the overwater fueling regulations and fueling operations for Terminal 5 were further researched and summarized.

5.1.2 Wastewater Discharges

Facilities in the Site vicinity with active industrial wastewater permits were identified through a database search of the Ecology Water Quality Permit Life Cycle System and communications with Ecology staff. Three active wastewater discharge permits were identified in the Site vicinity: Todd Pacific Shipyard, Shell Oil, and Nucor Steel. Todd Pacific Shipyard and Shell Oil are located across the West Waterway from the Lockheed West Site, and Nucor Steel discharges to the Longfellow Overflow Line. Copies of the permits and recent analytical data were obtained, summarized, and evaluated for remedy recontamination potential.

5.1.3 Combined Sewer Overflows

In some older urban areas, the sewer and stormwater systems are not completely separated. During major storm events, flow can exceed the capacity of the sewer system, and the overflow of combined sewage and stormwater is routed to overflow outfall and are called CSOs. In Seattle, Seattle Public Utilities manages 92 CSO locations and King County manages 38 CSO locations.

The SW Hinds Street Outfall (Seattle Public Utilities 099) is located near the head of the West Waterway and represents a CSO that is included in the City CSO permit. Longfellow Creek

discharges into the West Waterway through this outfall. It has been identified as a high priority for further assessment and improvements by the City of Seattle in part because of water quality problems in Longfellow Creek (refer to Figure 3-1).

King County operates two CSOs in the site vicinity including the Chelan Avenue (King County 036) and Harbor Avenue (King County 037) outfalls, which are also located near the head of the West Waterway. According to King County, these CSOs are considered to be controlled under the terms of their permit.

The source control reports identified the locations of CSO in the Site vicinity and included a summary and/or evaluation of permit requirements, water quality and sediment assessments pertaining to the CSO programs, and planned improvements.

5.1.4 Stormwater Discharges

Municipal and private industrial stormwater permits in the Site vicinity were identified through a database search of the Ecology Water Quality Permit Life Cycle System. The current and historical configuration of nearby stormwater drainage features including the SW Florida Street Outfall (and remainder of Terminal 5) and the Longfellow Overflow Line were summarized. The general stormwater permit and associated Stormwater Pollution Prevention Plan for Terminal 5 was obtained, summarized, and evaluated. The locations of permitted stormwater outfall locations at Terminal 5 were identified. Sediment chemical data from the vicinity of the SW Florida Street Outfall were summarized and evaluated to determine if this stormwater drainage feature represents a significant historic or ongoing source for recontamination.

The northern portion of current Terminal 5 stormwater system in the vicinity of the former shipyard uplands was field-verified during April 2009. The status of the decommissioned drainage system at the former shipyard uplands that was addressed during historical remediation of the former shipyard uplands was also field-verified.

5.1.5 Upland Contaminated Sites

Upland contaminated sites that border the West Waterway were summarized and evaluated for remedy recontamination potential. Of these sites, former shipyard uplands and PSR upland sites were deemed the most relevant to the Lockheed West Site based on their close proximity,

historical remediation activities, and ongoing groundwater chemical monitoring programs. Recent (fall 2008) and historical groundwater chemical and flow data for both sites were summarized and evaluated. As shown in Figure 3-1, the former shipyard uplands constitutes the upland area adjacent to the Lockheed West Site to the south and represents a remedial action area (RA-5) that is currently undergoing groundwater monitoring as part of the SWHP overseen by Ecology. The Port of Seattle is responsible for implementation of the groundwater monitoring program at the former shipyard uplands. A partitioning evaluation was performed using October 2008 groundwater data from the former shipyard uplands to determine if the groundwater concentrations would potentially recontaminate the Lockheed West Site remedy. The PSR Upland OU is located immediately west of the former shipyard uplands and the PSR Marine Sediment Unit is located immediately west of the Lockheed West Site (Figure 3-1). Recent (2008) groundwater monitoring data and the recently available (EPA, 2009b) 5-year review for the PSR site were summarized and evaluated.

5.1.6 Contaminated Sediment Sites and Sediment Transport

Several contaminated sediment sites are present in the Site vicinity (including the Pacific Sound Resources Mareine Sediment Unit, West Waterway OU, Todd Shipyard Sediment OU, and Lockheed Shipyard No. 1 Sediment OU) where remedial activities have been completed as well as the ongoing LDW sediment cleanup. Various aspects of these sediment sites were summarized and evaluated to determine the recontamination potential including the following: results of ongoing long-term cap monitoring programs, RI/FS results, and LDW sediment transport modeling. A qualitative comparison of the Lockheed West Site surface sediment results for pre-remedial investigation samples and more recent 2007 (remedial investigation samples) was also performed to identify contaminant concentration trends in surface sediment to help assess recontamination potential. Maintenance dredging was also evaluated as a potential source of in-water contaminants to the Lockheed West Site.

Site stability was also assessed as a line of evidence to assist in the evaluation of potential ongoing off-site sources. As part of this evaluation, wave analysis and other modeling for nearby sediment sites was assessed to provide an indication of the potential for re-suspension of sediment in the Lockheed West Site vicinity.

The sediment transport modeling results and sediment stability evaluation for the LDW are summarized in more detail in Section 6.0, Fate and Transport of Sediment and Sediment-Associated Chemicals, in this report.

5.1.7 Atmospheric Deposition

Various air quality and atmospheric deposition monitoring data for the South Seattle area were summarized as part of the source control evaluation. Air dispersion modeling results were also summarized in the *Source Control Evaluation Report*.

5.2 SOURCE CONTROL EVALUATION FINDINGS

The following sections describe the major source control findings. The findings for each major source type are presented with respect to the recontamination potential for the Lockheed West Site.

5.2.1 Overwater Uses and Spills

The documented recent history of spills in the West Waterway provides an example of normal risks of recontamination inherent in an industrial port setting. The Port operates three berthing areas at Terminal 5 where cargo is loaded over the water. Fueling of cargo vessels occurs in the West Waterway in the vicinity of Terminal 5. Fuel transfer operations occur from fuel barges to cargo ships rather than shore to ship. The current operations at Terminal 5 will continue into the foreseeable future. Currently, there is no commercial cargo handling or fueling overwater uses at the Lockheed West Site.

Overwater uses and spills represent a potential source and pathway for remedy recontamination at the Lockheed West Site. Some institutional controls (such as implementing best management practices for anchorage, fueling, and dredging) may be appropriate depending on the selected remedy at the Lockheed West Site and may restrict some future overwater uses of the property. Institutional controls and planned future uses of the Lockheed West Site are further evaluated as part of the FS.

5.2.2 Wastewater Discharges

The *Final Source Control Information and Data Gap Report* and the *Source Control Evaluation Report* include the wastewater discharge permits and recent chemical monitoring data for permitted sites including Todd Pacific Shipyard, Shell Oil, and Nucor Steel. The chemical monitoring programs for these sites overlap to varying degrees with Lockheed West COPCs (e.g., selected metals and PCBs) and are designed to monitor for site-specific wastewater discharges. For these reasons, the data are relevant for source control evaluation purposes.

A review of recent data (January 2006 to present) compiled from the Ecology Water Quality Permit Life Cycle System database shows that there have been no recent exceedances of the permit standards for the Todd Pacific Shipyard. Design modifications to the stormwater system and improved stormwater management practices there have been implemented as described in the Operations, Maintenance, and Monitoring Plan for that facility. Based on these findings, the discharge from the Todd Pacific Shipyard stormwater system represents a low likelihood of being a significant source for potential remedy recontamination at the Lockheed West Site (Tetra Tech, 2009b).

For the Shell Oil facility, there was a one-time failure to meet the pH criteria based on review of the recent data (January 2006 to present) compiled from the Ecology Water Quality Permit Life Cycle System database. Based on the analytical results, which meet the permit standards, and the location of the Shell Oil facility with respect to the Lockheed West Site (across the West Waterway and about 0.5 mile to the south), it appears that the Shell Oil facility represents a low likelihood of being a significant source for potential remedy recontamination at the Lockheed West Site (Tetra Tech, 2009b).

Copper and PCBs exceeded the permit standard on a couple of occasions over a 3-year period of monthly monitoring at the Nucor Steel facility based on review of recent data compiled from the Ecology Water Quality Permit Life Cycle System database. A sediment recontamination assessment was performed for the PSR sediment cap, which included a hydraulic and mass balance assessment and sediment sampling from catchbasins along the Longfellow Overflow Line alignment to assess the potential for recontamination of the PSR Marine Sediment Unit cap (Aspect, 2008a). According to Aspect (2008a), the sediment mass-balance results show that

calculated sediment deposition concentrations for zinc and PAH were below SQS chemical criteria, indicating a low potential for sediment recontamination of the PSR sediment cap from the Longfellow Overflow Line Outfall.

Based on the relatively small discharge and watershed characteristics of the Longfellow Overflow Line, its distance from the Lockheed West Site (about 1,000 feet), and the results of the PSR recontamination assessment, it appears that stormwater discharges from the Nucor Steel facility and the Longfellow Overflow Line have a low likelihood of being a significant source for potential remedy recontamination at the Lockheed West Site (Tetra Tech, 2009b).

5.2.3 Combined Sewer Overflows

The City and County CSOs represent a potential source/pathway for remedy recontamination. However, the CSOs appear to represent a relatively low likelihood for remedy recontamination based on their distance from the Lockheed West Site (about 1 mile). The CSOs also appear to represent a relatively low source-control priority for the Lockheed West Site based on the identification of potentially larger and/or more proximal potential sources. The City of Seattle and King County are also planning improvements for these CSOs. These improvements should reduce overflow events and contaminant loading to the West Waterway. The project team should consider performing periodic status updates for these CSOs to document improvements and summarize ongoing monitoring results.

Improvements to CSOs generally include creation of additional storage, treatment, and transfer piping capacity; improved management, monitoring, assessment, and system maintenance; and improved pollution prevention programs. During summer 2009, EPA (2009c,d) issued Compliance Orders of Consent to King County and the City of Seattle regarding their CSO discharge permits. The City of Seattle also has been required to address various maintenance and assessment items including preparation of various plans and inspection programs.

5.2.4 Stormwater Discharges

There are several facilities in the Site vicinity with general industrial NPDES stormwater permits as described in the *Source Control Information and Data Gap Report* and *Source Control Evaluation Report*. The closest of these facilities is Eagle Marine Services at Terminal 5. There

are four major stormwater conveyances at Terminal 5. The closest of these outfalls is the SW Florida Street Outfall that borders the southern portion of the Lockheed West Site.

The remedy recontamination potential for the SW Florida Street Outfall was further evaluated as part of the *Source C ontrol E valuation R eport*. The SW Florida Street Outfall represents a relatively low ongoing recontamination potential for the Lockheed West Site remedy, provided that Port operations in the vicinity of the drainage system do not significantly change. The following observations regarding the SW Florida Street Outfall were provided:

- A shoreline survey of the Terminal 5 frontage was performed during April 2009 in an effort to reconcile details regarding the layout of the current and former stormwater drainage system and as verification of an earlier shoreline inspection that was performed as part of the remedial investigation and summarized in the *RI Data Report*. Based on the inspection, the current stormwater drainage system at the former shipyard uplands drains to the SW Florida Street Outfall. The previous shoreline survey (Tetra Tech, 2008b) and Phoinix (2006) stormwater inspection noted the presence of miscellaneous piping along the shoreline. The piping found during the previous shoreline survey was consistent with observations made during the April 2009 survey. The observed piping did not appear to represent storm sewer piping based on construction and location. Only one of the miscellaneous pipes observed along the shoreline was draining a small trickle of water during the April 2009 site shoreline survey that likely represented seawater drainage during low tide.
- Sediment data were collected from near the SW Florida Street Outfall during the remedial investigation and were evaluated to assess whether historical discharges have resulted in a discernible contamination hotspot. Based on a comparison with the remedial investigation data, a contaminant hotspot could not be identified. Due to changes in configuration and current regulation of stormwater discharges, future releases to the drainage system will likely be significantly less than historical releases.
- The Stormwater Polution Prevention Plan for Terminal 5 does not include ongoing chemical monitoring of the SW Florida Street Outfall. Recent water quality results (January 2006 through the present) for Eagle Marine Services at the Terminal 5 Outfall show that zinc (maximum of 780 micrograms per liter [µg/L] during July 2008) consistently exceeded the benchmark screening value (117 µg/L) specified in the Stormwater Polution Prevention Plan. However, this monitored outfall is about ½ mile from the Lockheed West Site and is too far away to represent a high likelihood of remedy recontamination for the Lockheed West Site.

5.2.5 Upland Contaminated Sites

Ongoing groundwater chemical monitoring is being performed at both the former shipyard uplands (RA-5) of the SWHP as well as the neighboring PSR Superfund site. The fall 2008 results were obtained for both sites and evaluated in detail in the *Final Sour ce C ontrol Evaluation Report*; they are summarized briefly below for convenience.

The results for the former shipyard uplands showed that arsenic, benzo(a)anthracene, and chrysene were detected in groundwater at low concentrations above surface water screening levels for human health for consumption of organisms. The detected concentrations of arsenic were within the range of arsenic concentration for SWHP background wells. A partitioning evaluation was performed using these data. The evaluation contained the conservative assumption that the upland groundwater concentrations would be present in sediment porewater within the Site to which site receptors are exposed. The evaluation showed that the concentrations of these chemicals recently measured in groundwater at the former shipyard uplands do not represent an unacceptable potential risk; therefore, contaminated groundwater discharge from the former shipyard uplands does not currently represent a significant potential for remedy recontamination at the Lockheed West Site (Tetra Tech, 2009b).

The interim groundwater monitoring report and 5-year review for the PSR site (EPA, 2009e,b) contain information that indicates that the continued use of the ROD-specified groundwater alternate concentration limits for the PSR site is inappropriate. Based on review of the 2008 data, an increasing trend was observed in PAH and/or PCP groundwater concentrations in wells outside the slurry wall constructed as part of the PSR uplands remedy and nearest the former shipyard uplands (wells RW-12s, MW-15IR, and MW-15SR). This data set also represents the first occurrence of DNAPL in an intermediate well (well MW-15IR) located seaward of the slurry wall near the former shipyard uplands. Given these findings, there is uncertainty about the long-term protectiveness of the PSR upland remedy. EPA is currently responsible and is continuing to perform ongoing monitoring of the PSR uplands site. Monitoring results for the most recent June 2011 sampling effort will be available in 2012.

Various factors minimize the likelihood of remedy recontamination for the Lockheed West Site from the PSR site (Tetra Tech, 2009b). The western edge of the Lockheed West Site is at least

500 feet away from the affected PSR upland wells. It is also unclear if the groundwater flow path from the contaminated PSR wells near the former shipyard uplands is in the direction of the Lockheed West Site; October 2008 chemical data for the former shipyard uplands do not show a groundwater contamination problem (Tetra Tech 2009b). These data represent the initial sampling round for the Southwest Harbor Project Phase II Confirmation Program and are summarized in detail in the *Source Control Evaluation Report*.

5.2.6 Contaminated Sediment Sites and Sediment Transport

The Lockheed West Site potentially receives deposits of sediment transported from off-site sources that contain concentrations of contaminants above likely Site cleanup goals. These off-site sediments likely originate from several sources and control of these sources would be challenging.

The Lockheed West Site is situated at the mouth of the West Waterway, which is an actively maintained waterway used for navigation, commercial, and industrial purposes. The Lower Duwamish Waterway discharges to Elliott Bay through the West Waterway. There are several contaminated sediment sites nearby (Lockheed Shipyard No. 1 OU, West Waterway OU, Todd Shipyard Sediment OU, and Pacific Sound Resources Marine Sediment Unit) where remedial activities have been completed. The Lower Duwamish River, West Waterway, and Elliott Bay are potential sources of sediments containing contaminants at concentrations above the potential cleanup goals for the Lockheed West Site.

Data from ongoing monitoring, modeling, and recent remedial investigation provide multiple lines of evidence on the potential for sediment recontamination from off-site sources to the Lockheed West Site. These lines of evidence were evaluated and are summarized below. The *Source Control Evaluation Report* provides a more detailed summary of the LDW sediment transport model as it relates to the potential for remedy recontamination at the Lockheed West Site. It is acknowledged that this draft model result was developed by the Lower Duwamish Waterway Group, and not a regulatory agency, and is subject to substantial uncertainty. Model output for the LDW (Windward and QEA, 2008) indicate that approximately 50 percent of the sediment load entering the system (approximately 100,000 metric tons per year [mt/yr]) goes into the West Waterway/East Waterway, with approximately 80 percent of the flow into the West

Waterway. The upstream contaminant concentrations associated with these suspended sediments are estimated at 50 parts per billion (ppb) for PCBs, 10 ppm for arsenic, and 170 ppb for cPAHs in the draft LDW FS (EPA and Ecology, 2009), although EPA, in comments on that FS, raised questions regarding these input values and requested that they be revised. Even with expected revisions, these concentrations are above the RBTCs calculated for the Lockheed West Site (less than 1 µg/kg dw PCBs, 0.000023 mg/kg dw arsenic, and 0.22 µg TEQ/kg cPAHs). Refer to Section 9.0 for further discussion of RBTCs and background concentrations. It is uncertain how much of the LDW suspended sediments entering the West Waterway potentially ends up being deposited at the Lockheed West Site. However, based on a conservative assumption that suspended sediments from the Lower Duwamish Waterway are characterized by contaminant concentrations equivalent to the upstream input, the potential for these sediments to be a recontamination source is high.

Ongoing monitoring at sites where sediment remedial actions have been completed provides an indication of contaminant levels in recently deposited materials. Table 5-1 summarizes surface sediment and sediment trap results for nearby sediment cleanup sites including Todd Pacific Shipyard, Lockheed Yard 1, PSR, and the West Waterway. In the West Waterway, the cap monitoring results for sediment deposited on caps at the LSSOU site and the TSSOU site show that concentrations for select COCs in the surface sediments are above the RBTCs for the Lockheed West Site, indicating a potential for sediment recontamination. The results of monitoring at the adjacent PSR site also indicate that newly deposited sediments contain contaminants at concentrations above the Lockheed West Site RBTCs.

An evaluation of co-located surface sediment samples collected at the Lockheed West Site between 1985 and 2008 provides a qualitative trend analysis for the Site. This evaluation shows that while there was spatial variability in the trends, several of the shipyard-related contaminants (arsenic, copper, lead, and zinc) were found to decrease over time, while the concentrations of mercury and PCBs were either unchanged or increasing. This difference in trends between the contaminants is an indication that the Lockheed West Site surface sediments are potentially being impacted by off-site source deposits. This evaluation is discussed in more detail in Section 6.1.2.3.

Dredge records along with the bathymetric survey completed in 2006 were reviewed to qualitatively evaluate sedimentation and sediment redistribution at the Site. The bathymetry results show that the sediment surface is stable at the dredge permit elevations (approximately 45 feet MLLW in areas of the last dredge permits). The bathymetry data also provide clear resolution of the historical bottom features at the Site. The evidence indicates that sedimentation rates at the Site are relatively low and that sediment redistribution across the Site is also low. A wave analysis for the Site supports the general conclusion that overall the potential for movement of site sediments is low.

The evaluation of multiple lines of evidence indicates that there are potential off-site sources for sediment recontamination at the Lockheed West Site. These sources are uncontrolled and would likely be administratively difficult to address. Uncertainty exists on the potential magnitude of the impact from these sources to the Lockheed West Site sediment remedy. The *Source Control Evaluation Report* shows that the potential source contaminant concentrations are likely above Lockheed West Site RBTCs and background concentrations for some chemicals. Refer to Section 9.0 for further discussion of RBTCs and background concentrations. It is recommended that sediment recontamination via in-water sources be acknowledged as an uncertainty and evaluated as part of the risk-management decision for remedy selection.

5.2.7 Atmosperic Deposition

From a source control standpoint, air deposition represents a non-point source contribution that is difficult to conclusively evaluate and administratively address. Based on review of existing data from the station near the Duwamish River about 1 to 1.5 miles southwest of the Site, PCBs, PAHs, phthalates, and VOCs are present in atmospheric dust. These results suggest that atmospheric deposition is a potential source of contaminants to the Site sediments, but there is a high degree of associated uncertainty. The recontamination risk from atmospheric deposition appears to be low given the small remediation area where atmospheric deposition will directly occur and the fact that area-wide atmospheric deposition contributes to other potential sources of recontamination such as stormwater runoff, CSO discharges, and in-water sediment transport that are also evaluated in this report. It is recommended that atmospheric deposition be acknowledged as an uncertainty associated with the risk-management decision for remedy selection and that further assessment of this source is not warranted.

5.3 SUMMARY OF REMEDY RECONTAMINATION POTENTIAL

Overall, the likelihood of remedy recontamination of sediments to levels that exceed the Lockheed West Site RBTCs for some chemicals (e.g., PCBs, cPAHs, and arsenic) and background concentrations (refer to Section 9.0 for further discussion) is high based on an evaluation of recent sediment monitoring data for nearby sediment cleanup sites. The likelihood of sediment recontamination above the SQS standards that represent promulgated sediment criteria in Washington for protection of benthic invertebrates is relatively low based on review of ongoing sediment monitoring data. The conditions and dynamics that contribute to the potential for recontamination remain the same, regardless of clean-up levels. The potential sources of remedy recontamination are outside of the direct control of Lockheed Martin and include overwater uses and spills, wastewater discharges, CSOs, stormwater discharges, upland contaminated groundwater discharges, and contaminated in-water sediment transport and deposition.

A brief summary of the relative potential for remedy recontamination at the Lockheed West Site by the various sources is presented below. The sources have been ordered from greatest to least potential based on relative risk, data gaps or uncertainties, and physical proximity to the Site:

- **In-Water Contaminated Sediment Transport and Deposition.** This source represents a relatively high likelihood of remedy recontamination for selected COCs at low-level concentrations above the RBTC, but not the SQS (refer to Section 9.0).
- **Contaminated Groundwater Discharges from Nearby Upland Sites.** This source represents a relatively low likelihood of remedy recontamination based on the most recent groundwater data collected from the former shipyard uplands and the relatively large distance to the Lockheed West Site from the PSR upland site. However, the EPA 5-year review finding for the PSR site (EPA, 2009b) deferred a determination of long-term remedy protectiveness and recent PSR groundwater monitoring results show potential seaward migration of DNAPL and dissolved contamination near the western boundary of the former shipyard uplands.
- **Stormwater Discharges.** This source represents a relatively low likelihood of remedy recontamination based on: 1) sediment data collected near the SW Florida Street Outfall during the Lockheed West RI/FS, 2) reconfiguration of the SW Florida Street drainage system, 3) implementation of the former shipyard upland cleanup remedy that included cleaning and plugging of the historical stormwater drainage system at the former shipyard

uplands, and 4) the current property use at Terminal 5 (container storage and/or vacant). Chemical monitoring of surface water discharges at the SW Florida Street Outfall has not been performed.

- **Overwater Uses and Spills.** This source represents a relatively low likelihood of remedy recontamination with the exception of an unforeseen accident. The history of spills in the general area appears to be normal for an urban, industrial setting. Vessel-to-vessel fueling operations associated with shipping activities at Terminal 5 occur near the Lockheed West Site.
- **CSO Discharges.** This source represents a relatively low likelihood of remedy recontamination based on the relatively large distance between the CSO outfalls and the Lockheed West Site.
- **Wastewater Discharges.** This source represents a relatively low likelihood of remedy recontamination based on a review of the ongoing chemical monitoring associated with the NPDES permits and the relatively large distance between the discharge outfalls and the Lockheed West Site.
- **Atmospheric Deposition.** This source represents a relatively low likelihood of remedy recontamination given the small remediation area where atmospheric deposition will directly occur, and the fact that area-wide atmospheric deposition contributes to other potential source of recontamination such as stormwater runoff, CSO discharges, and in-water sediment transport.

Table 5-1.
Surface Sediment and Sediment Trap Results Summary Nearby Sediment Sites

Parameter	Arsenic	Copper	Lead	Mercury	Zinc	PCBs	TBT	LPAHs	HPAHs	cPAHs
Screening Levels										
SQS (mg/kg dry wt)	57	390	450	0.41	410	0.13	NA	5.2	12	NA
RBTC (mg/kg dry wt)	0.000023	35	10	0.41	410	0.00011	0.017	NA	NA	0.00022
Todd Pacific Shipyard	Post dredge sediment 2004/2005[1/]									
Minimum Concentration	< 7	12	3	< 0.1	26	< 0.02	< 0.0059	< 0.007	< 0.007	NA
Maximum Concentration	25	87	49	**0.53**	167	< 0.02	0.048	0.55	1.448	NA
Number locations included	10	10	10	10	10	10	10	10	10	NA
Number above SQS	0	0	0	2	0	0	NA	0	0	NA
Number above RBTC	10	3	5	2	0	10	2	NA	NA	NA
Monitoring criteria										
DL	0.1	0.2	0.1	0.05	0.6	0.02	NA	NA	NA	NA
Evaluation Criteria	57	390	540	0.41	410	0.13	1.335	5.2	12	NA
Lockheed Yard 1	Surface sediment 2007 - 2010[2]									
Minimum Concentration	< 6	13.7	11	0.03	41	0.0233	NA	0.012	0.884	NA
Maximum Concentration	16	111	130	0.38	214	0.149	NA	0.255	2.356	NA
Number locations included	5	5	5	5	5	5	NA	5	5	NA
Number above SQS	0	0	0	0	0	2	NA	0	0	NA
Number above RBTC	5	5	5	0	0	5	NA	NA	NA	NA
Pacific Sound Resources	OMMP Monitoring 2007[3/]									
Minimum Concentration	4.25	9.1	3.42	0.021	16.9	< 0.002	NA	0.023	0.101	NA
Maximum Concentration	23.9	212	109	0.243	**452**	**0.14**	NA	1.55	6.88	NA
Number locations included	5	5	5	5	5	5	NA	5	5	NA
Number above SQS	0	0	0	0	1	1	NA	0	0	NA
Number above RBTC	5	1	2	0	1	5	NA	NA	NA	NA
West Waterway	Investigation surface sediments 2007[4/]									
Minimum Concentration	6.08	28.2	19.8	0.178	48.1	0.072	0.052	0.19	0.921	0.144
Maximum Concentration	32	**840**	192	**0.998**	304	**1.41**	4.5	3.74	18.25	2.54
Number locations included	8	8	8	8	8	8	8	8	8	8
Number above SQS	0	2	0	5	0		NA	0	1	NA
Number above RBTC	8	6	8	5	0	8	8	NA	NA	8

1/ Operation, Maintenance, and Monitoring Plan, Todd Shipyards, Sediment Operable Unit, Prepared for Todd Pacific Shipyards Corporation, Prepared by FLOYD | SNIDER, August 1, 2007.
2/ 2011 Operation, Monitoring and Maintenance Report, Remedial Action for the Lockheed Shipyard No. 1, Sediments Operable Unit (LSSOU) of Harbor Island Superfund Site, Seattle, Washington, Prepared by Tetra Tech, February 2012.
3/ 2007 Long-Term Monitoring, Pacific Sound Resources Superfund Site, Seattle Washington, Monitoring Report Revised Draft, February 26, 2008, prepared for the USACE, prepared by SAIC.
4/ Remedial Investigation Data Report, Draft, Lockheed West Seattle Superfund Site, Tetra Tech, May 2007.

Results Underlined exceed Lockheed West RBTC values.
Results in **Bold** exceed Washington State SQS values.

SQS = Sediment Quality Standards
cPAH = Carcinogenic polynuclear aromatic hydrocarbons
TBT = Tributyltin
HPAH = High molecular weight polynuclear aromatic hydrocarbons
LPAH = Low molecular weight polynuclear aromatic hydrocarbons
OMMP = Operations, maintenance, and monitoring plan
PCBs = Polychlorinated biphenyls
RBTC = risk-based threshold concentration

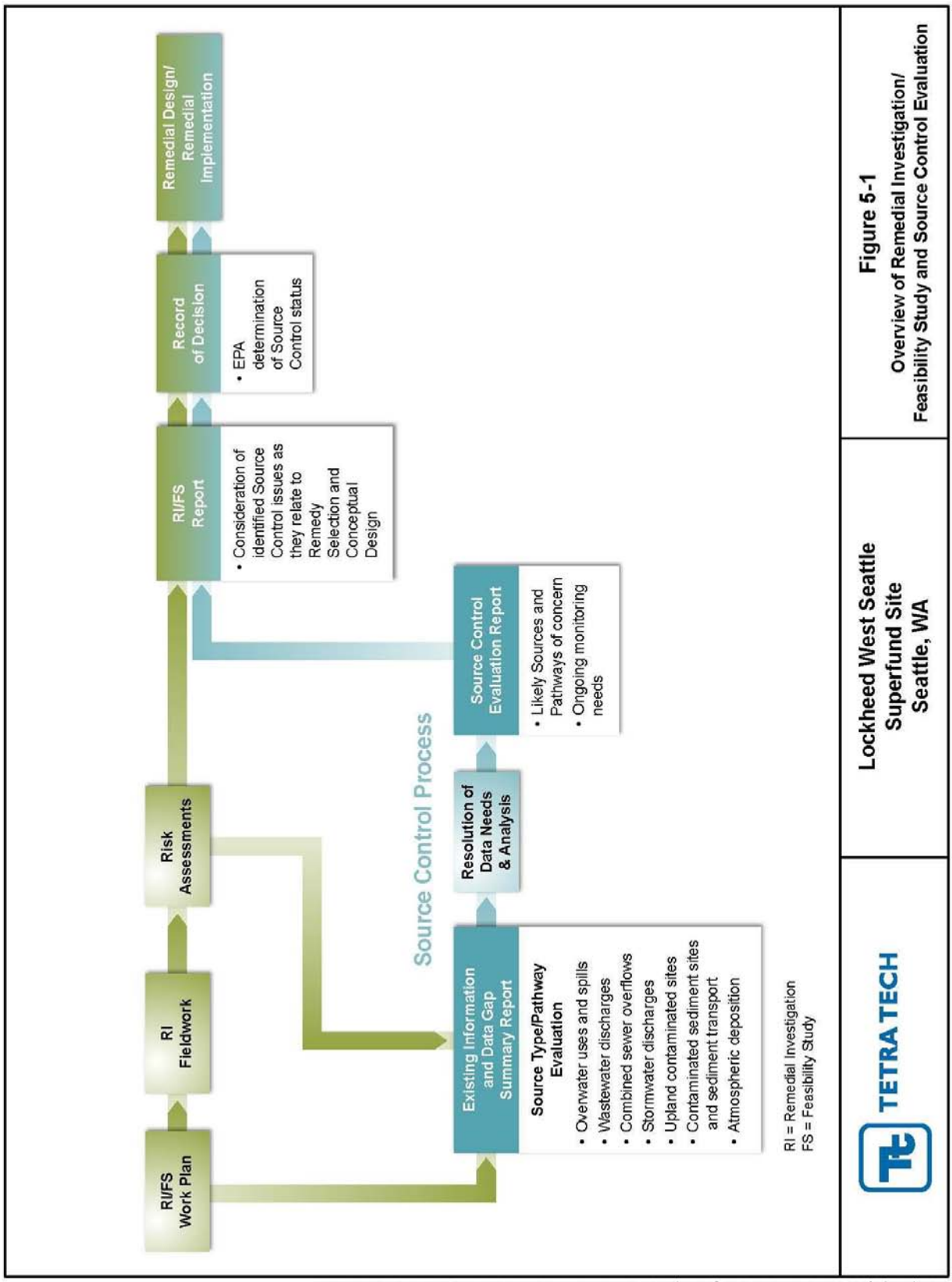


Figure 5-1
Overview of Remedial Investigation/ Feasibility Study and Source Control Evaluation

SECTION 6
Fate and Transport of Sediment and Sediment-Associated Chemicals

This section describes the physical, chemical, and biological processes that influence the fate and transport of chemicals in the sediments and water column of the Site. These processes are important for the deposition of contamination in the sediments, migration of contaminants, and the likely exposure pathways to receptors. Information on these processes has been compiled from various sources including *Soil Screening Guidance: A User's Guide* (EPA, 1996) and *Basic Concepts of Contaminant Sorption at Hazardous Waste Sites* (EPA, 1990). The discussion of the fate and transport processes for the Site is focused on current sediment conditions and the processes that affect contaminant availability to receptors, movement of contaminated sediments around and off of the Site, and those processes that have a potential to impact remedial alternatives.

Ongoing sources of contaminants to the Site sediments are limited, with most upland sources controlled or not found to present a significant potential for contributing new contamination (Tetra Tech, 2009a,b). The source control evaluation (Section 5.0) concluded that off-site in-water sources are potential sources of contaminants and Site sediments are expected to reach a long-term equilibration at levels that are above the RBTCs.

For the Site, the primary focus of the discussion is on sediment-related processes such as physical transport and partitioning between sediment particles and porewater. This discussion of fate and transport processes is organized in four main subsections, corresponding to the major media and associated fate and transport processes at the Site as follows: 1) physical sediment transport, 2) surface-mixed sediment layer and associated porewater, 3) surface water, and 4) biota. For each of these four categories, relevant fate and transport processes are discussed for

each of the general chemical groups and specifically for the COCs identified as risk drivers in the *ERA* and *HHRA* (Section 7.0). The identified risk-driver contaminants include PCBs, dioxins/furans, cPAHs, arsenic, copper, lead, mercury, and TBT.

6.1 SEDIMENT PHYSICAL TRANSPORT PROCESSES

Many of the chemicals detected in the sediments (e.g., PCBs and PAHs) are hydrophobic chemicals that strongly adsorb to sediment particles. In particular, these compounds partition to cohesive and fine-grained particles (i.e., silts and clays); therefore, the physical transport of sediments, especially silts and clays, is one of the dominant processes that impacts the transport and distribution of these chemicals.

Sediment movement into, within, and through the Site occurs as suspended load in the water column and as bedload along the water-sediment interface. Suspended particulate transport in the water column refers to the transport of solids suspended in the surface water. Cohesive or fine-grained sediments generally move as suspended load. Bed-load transport of sediment refers to sediment transported along or very close to the sediment bed (as described in Section 6.1.2.1). Non-cohesive sediments (sand and coarser material) typically move as bedload; however, a variable fraction of non-cohesive sediments move as suspended load as a function of the flow regime (i.e., as flows increase, a larger fraction of non-cohesive sediment will move in suspension). The movement by re-suspension, suspended load, and bedload transport of sediments in the study area is controlled by natural and anthropogenic forces that affect water movement and the bottom shear stresses. The following discussion of physical transport is divided into a broad-scale area-wide transport summary and a site-specific evaluation.

6.1.1 Area-Wide Sediment Physical Transport

The Lockheed West Site is located adjacent to an active waterway (West Waterway) and near several sites where sediment cleanup activities have occurred or will occur in the future. As established in Section 5.0, sediment from the West Waterway and from some of the nearby contaminated sediment cleanup sites (e.g., PSR) are likely transported onto the Lockheed West Site.

The Lockheed West Site sits at the mouth of the West Waterway through which approximately 80 percent of the water exiting the Duwamish River flows (Weston, 1999). A sediment transport model developed for the LDW (Windward and QEA, 2008; QEA, 2008) contained an estimate that approximately 50 percent of the suspended sediment load entering the Lower Duwamish Waterway is transported downstream (approximately 100,000 mt/yr). With an estimated 80 percent of this load being transported to the West Waterway (Weston, 1999), it is likely that some of the Lower Duwamish Waterway suspended sediments are deposited at the Lockheed West Site. As summarized in Section 5.0, performance monitoring data from nearby sediment sites indicate that suspended and bedload sediments carry low-level contamination for selected chemicals at or below the SQS levels but above Lockheed West Site RBTCs and background concentrations. Refer to Section 9.0 for further discussion of RBTCs and background concentrations.

As discussed in Section 2.2.6, the general circulation pattern in the inner portion of Elliott Bay is counterclockwise with Duwamish River flows discharging to the bay. This pattern can create eddies at the mouth of West Waterway during high river flows and ebb tides. The combination of tidal and river flows results in a consistent surface flow across the Site from west to east.

A sediment transport analysis was completed by URS (2002) as part of the Final Design submittal to EPA for the PSR Marine Sediment Unit cap design. The Marine Sediment Unit is adjacent to the Site to the west in Elliott Bay. The sediment transport analysis included collection of bottom current speed and direction data at two locations in the Marine Sediment Unit. Mean current speeds in the Marine Sediment Unit were measured to be in the range of 2 to 3 cm/sec and 99.9 percent of the measured current speeds were 12 cm/sec or lower. Wind data were analyzed to identify potential correlations with the observed current speeds. No correlation was identified; however, the analysis concluded that there is no indication that significant bottom currents would be induced at the Marine Sediment Unit during storm events. Conditions at the Lockheed West Site are similar to those at the PSR Marine Sediment Unit and potential sediment transport and current conditions are likely similar as well. A screening-level analysis was used to assess the need for sediment grain-size restrictions to resist erosion in subtidal areas of the PSR Marine Sediment Unit. This analysis concluded that the fine-grained cap materials placed at the

Marine Sediment Unit would be stable at current velocities less than 20 cm/sec. This information will be used at the Lockheed West Site during the design phase.

Sediment transport is influenced both by currents and bathymetry. Bottom currents in Elliott Bay move in a clockwise circular motion (GeoSea, 1994) and tend to move sediment along depth contours. Sediment movement driven by the bottom current would result in sediments from the areas east of the Site in Elliott Bay potentially being deposited onto the Site. A study for the Elliott Bay/Duwamish Restoration Program (Ecology, 1995) found that net sedimentation for the Seattle waterfront ranged from 0.06 to 0.12 centimeter per year. These general conditions along with the evaluation of surface sediments described in Section 6.1.2 below indicate that the Lockheed West Site is a net depositional area characterized by a relatively low depositonal rate and relatively stable sediments

6.1.2 Site-Specific Sediment Physical Transport Evaluation

To evaluate the potential for sediment re-suspension and migration at the Lockheed West Site due to hydrodynamic forces, a wave analysis and evaluation were completed along with an evaluation of the Site bathymetry. In addition, a summary of the chemical trend analysis of on-site surface sediments performed to determine if chemical data show evidence of transport is presented in this section. A seismic evaluation for the Site was completed and is summarized in Section 6.1.2.4; the full evaluation is also included in Appendix H.

6.1.2.1 Surface Sediment Dynamics

Particles that settle out or move along the bottom are subjected to a wide range of physical, biological, and chemical processes. A wave analysis and evaluation were completed as part of the *Source Control Evaluation Report*. This evaluation considered the shear stress exerted on Site sediments by hydrodynamic forces to assess the potential for sediment movement.

As water flows over a sediment bed, the flow exerts a shear stress on the bed due to viscosity and turbulence. From a static equilibrium perspective, shear stress on sediment particles is balanced by the forces of gravity, inter-particle friction, and cohesion. When shear stress exerted by water flow exceeds the balancing forces, sediment particles move. The shear stress at which this begins to occur is known as the critical shear stress for erosion, or erosion threshold (USACE, 2006).

The wave evaluation consisted of two steps: 1) calculate the shear stress exerted on Site sediments by hydrodynamic forces using Todd Shipyard wave analysis results and site-specific sediment properties, and, 2) evaluate estimates of maximum near-bottom shear stress for Lockheed West Site sediments relative to critical shear stress estimates for Site sediments. This comparison is used to assess the potential for sediment movement.

The first step in this analysis was to estimate the hydrodynamic forces associated with extreme storm events exerted on bottom sediments. This analysis was based on readily available data and evaluates the potential of Site sediments to mobilize due to wind-wave generated bottom forces only. Using wind-wave design criteria for extreme design storm events at the nearby Todd Shipyard Sediment OU (Table 6-1), the potential of Site sediment to mobilize due to wind-wave generated bottom forces was evaluated. Other phenomena that can generate bottom forces that could mobilize sediments, such as currents and propeller wash, were not specifically evaluated for the Site. Analyses conducted for the nearby PSR site (see above) and the LSSOU (see Section 2.2.6) were used as surrogates for the Site for these other phenomena.

Wind-wave generated bottom velocities and associated shear stresses were determined using the procedures outlined in the USACE (2006) *Coastal Engineering Manual* (CEM). The calculation of maximum, near-bottom velocity and shear stress require, as input parameters, a representative grain size for the sediment of interest. In addition, the calculation of critical shear stress using the USACE CEM methodology requires an estimate of the sediment specific gravity. Table 6-2 provides parameters that were obtained from a summary of data in the Lockheed West Site project database. The calculated wind-wave induced, near-bottom, maximum velocity and shear stress values for the Lockheed West Site are summarized in Table 6-3.

The second step of the evaluation is to compare the maximum near-bottom shear stress to estimates of the critical shear stress for the sediment. The critical shear stress is an estimate of the threshold shear stress necessary to cause sediment particle movement. If the maximum near-bottom shear stress is less than the critical sheer stress, then the potential for sediment movement from a 5-year or 25-year wave event would be low.

Shear stress for Site sediments was determined using methods for non-cohesive sediments, as outlined in the USACE (2006) CEM. This method is based purely on grain size of sediment and

ignores effects of cohesive forces. However, as a point of comparison it provides a conservative, low estimate of critical shear stress. The critical shear stress of Site sediments, as estimated using equations III-6-47 through III-6-49 of the USACE (2006) CEM, is 0.06 Pascal (Pa).

The maximum near-bottom shear stress exerted by the 5-year and 25-year storm events is 0.12 and 0.27 Pa, respectively. Both values are larger than the critical shear stress determined using methodology presented in Part III of the USACE (2006) CEM. This implies the sediment may be mobilized by a 5-year storm event, or greater; however, this analysis potentially overestimates the likelihood of mobilization from a 5-year storm because the estimate of critical shear stress neglects the cohesiveness of the sediment particles.

A more appropriate estimation of critical shear stresses is presented in the *Sediment Transport Analysis Report* (Windward and QEA, 2008) for the LDW. The sediment critical stress values were determined through Sedflume testing and analysis. Although the Lockheed West Site sediments may differ in composition from LDW sediments, these data are the best available for comparison. The range of critical shear stresses determined for LDW sediments using Sedflume testing was 0.16 to 0.56 Pa. These critical shear stress values are much larger than the single 0.06 Pa value calculated for the Lockheed West Site using the USACE CEM methodology. A comparison of the LDW critical shear stress values to the calculated near-bottom shear stress values for Lockheed West Site suggests a low potential for mobilization under either a 5-year or 25-year storm event.

6.1.2.2 Lockheed West Site Bathymetric Data Summary and Evaluation

A review of the high-resolution Site bathymetry (Tetra Tech, 2006) shows distinct bottom features and artifacts of past dredging events that occurred many years in the past. The presence of these features in the recent bathymetry survey suggests that the bottom surface has not changed substantially and erosion and redistribution processes are minimal in the area of the Site. This supports the conclusion in the previous section that the potential for movement of Site sediments is low.

Historical dredging information was reviewed along with the results of the bathymetric survey completed in May 2006 (Tetra Tech, 2006). The last dredge permits associated with the Site,

from 1954, indicate that areas of the Site were dredged to approximately elevation -45 feet MLLW in the areas of the dry dock berths. The high-resolution bathymetry collected in 2006 showed that the sediment surface elevation in these areas of the Site ranged between -50 and -40 feet MLLW. The bathymetric map of the Site also shows the details of the historic dredging that occurred at the Site and physical outlines of the dredged surfaces at the shipyard and in the adjacent West Waterway (Figure 4-9). The bathymetry data and clear resolution of the historical bottom features provide evidence that the sediment infill rate is relatively low and that overall movement of Site sediments is low.

6.1.2.3 Lockheed West Site Sediment Chemical Trend Analysis

Transport and deposition of sediments to the Lockheed West Site was identified as a potential source of recontamination at the Site. As part of the *Source Control Evaluation Report*, the status of this potential source mechanism was generally evaluated by review of time-concentration trends that compare the detected concentration of chemical contaminants at surface sediment sampling locations in given areas of the Site over time. This evaluation provides an indication of the impact of these sources on the Site and is summarized below.

One of the preliminary findings of the *Source Control Information and Data Gap Report* is that since the closure of the shipyard, upland areas have been remediated and, based on ongoing monitoring, there are no onshore sources of contaminated sediment to the offshore area of the Lockheed West Site. The Site is, however, subject to receiving sediments transported from in-water sources including the adjacent West Waterway and Elliott Bay as the result of wave and current action.

Assuming that there are no current onshore sources of contaminants to sediments to the Site and that there are no significant differences in the geochemical behavior in the environment between the parameters evaluated, the surface sediment concentrations would all be expected to exhibit similar time-concentration trends. In other words, if the Site receives sediment from off-site that does not contain chemical contaminants, it would be expected that overall surface sediment concentrations will decrease over time. In contrast, transport and deposition of sediments containing chemical contaminants onto the Site will tend to maintain elevated chemical concentrations at the surface or increase surface concentrations over time if the incoming

sediment has higher concentrations of chemicals than the Site sediments. The actual magnitude of the trend (i.e., either increasing or decreasing) would be dependent on the relative concentrations of the incoming and Site sediments and the transport mechanisms occurring at the Site. The trends may also vary spatially across the Site. Overall time-concentration trends showing that surface concentrations increased over time would provide evidence of ongoing sources of contaminated sediment with elevated concentrations to the Site. Static time-concentration trends are less definitive and could be evidence of transport and deposition of contaminated sediments or low sedimentation rates resulting in no burial of historically contaminated surface sediments.

The details of the evaluation can be found in the *Source Control Evaluation Report*. Six indicator chemicals (i.e., arsenic, copper, lead, mercury, zinc, and PCBs) were used to evaluate chemical concentrations over time. Metals were selected as indicator chemicals due to their relation to the historic shipyard operations as well as their adsorptive properties and environmental persistence. PCBs were included because they are a COC for the LDW, located upstream of the Lockheed West Site and a potential source of sediments to the Site.

The geographic distribution of the time-concentration trend at the Site is shown on Figure 6-1. Generally, the time-concentration trend distributions for arsenic, copper, lead, and zinc are similar and show an overall decrease in concentrations in the central part of the Site. The general pattern of decreasing concentrations indicates that the sediment transported to and deposited at the Site does not exhibit elevated concentrations of these contaminants.

The geographic distributions of the time-concentration trend for mercury and PCBs are similar to each other and directly contrast those observed for arsenic, copper, lead, and zinc. Mercury and PCBs generally increase over time in the central part of the Site. This time-concentration analysis suggests that sediments transported to and deposited at the Lockheed West Site are potential ongoing sources of mercury and PCBs.

6.1.2.4 Seismic Stability of Lockheed West Site Sediments

A seismic stability analysis was conducted to evaluate the potential for sediment movement from the Site (Appendix H). Events and outcomes assessed included liquefaction susceptibility and initiation; liquefaction-induced deformation; slope stability for current conditions, 108-, 475-,

and 2,475-year seismic events; and earthquake-induced displacement. Using conservative assumptions both in peak ground accelerations of the analyzed seismic events and in liquefaction potential of subsurface sediments, the findings indicate that excessive deformation and ground movement intersecting contaminated soils is unlikely in the Site footprint for a 108-year event but is likely for 475-year and 2,475-year events. When ground movement intersecting contaminated soils is predicted, lateral displacements and sediment movements were predicted to be in the range of 1 to 20 feet where corrective measures, such as cap repair and/or replacement, would be feasible. Based on the liquefaction-induced deformation analysis, there exists a risk of potential upwelling, exposure, and spreading of contaminated sediments beneath the capped areas due to liquefaction; however, the hazard is expected to be localized and again corrective measures, such as cap repair and/or replacement, would be feasible.

The Lockheed West Site setting, with flat to 2 percent slope bottom profiles, is different than the areas in the Duwamish River delta near Elliott Bay and Harbor Island where some landslides have historically occurred; a review of historical slides did not indicate any large-scale flow slides extending into the Site. Previous seismic stability analyses of the Duwamish River delta near Elliott Bay and Harbor Island indicate that soil liquefaction and ground failure of native deltaic deposits are likely during moderate to large earthquake events. A large-strain flow failure may also occur at the delta front along the northern end of Harbor Island under an earthquake scenario for the City of Seattle (Kayen and Barnhardt, 2007). A USGS study mapped southern Puget Sound delta fronts after the 2001 Nisqually earthquake (Gardner et al., 2001) including a series of large historic landslides. The closest historic landslides observed are within 1 km of the Site, about 1,500 feet from the delta shelf. During the 2001 Nisqually earthquake, peak ground acceleration with a magnitude similar to 108- and 475-year analyzed events was measured at Harbor Island. Liquefaction-induced hazards including a potential flow slide could have occurred under a seismic event of such magnitude. However, post-earthquake bathymetry surveys in the vicinity of the Lockheed West Site do not indicate any recognizable effect of liquefaction, slope failures, or flow slides. While the seismic evaluation does not suggest the occurrence of a large-scale flow slide that may affect the stability of contaminated sediments, a potential risk for a flow slide exists for the Site and is applicable to the FS analysis. Refer to Appendix H for details of the seismic evaluation conducted for the Site.

6.2 SEDIMENT AND POREWATER FATE AND TRANSPORT PROCESSES

The following subsections discuss the sediment and porewater fate and transport processes relevant to risk-driver contaminants detected in the sediments at the Site. The organic risk-driver contaminants detected in the Site sediments are generally hydrophobic and will tend to be sorbed to the sediment particles. The risk-driver metals also are expected to sorb to fine-grained sediment particles. A general discussion of organic and inorganic chemical behavior in sediment and porewater is presented, followed by a discussion of RI results for empirical data to help assess the relative importance of the various processes at the Lockheed West Site for the risk-driver contaminants.

6.2.1 Chemical Distribution between Sediment and Porewater

In the sediment and porewater environment, the distribution of a chemical between the solid and aqueous phases is among the most important physiochemical processes affecting its migration, bioavailability, and half-life. The equilibrium partitioning of a chemical between water (dissolved aqueous phase) and solid (sorbed to sediment or associated organic matter) is often generally described by a solid/water distribution coefficient (K_d);.

$$K_d \approx (C_s/C_w)$$

Where:

- C_s = the concentration of the chemical associated with solids
- C_w = the aqueous concentration of the chemical

Major processes and environmental factors that control this distribution are discussed below in general terms for organic and inorganic chemicals. For additional perspective, partitioning values derived from Site-specific data have been compared to published literature values for relevant risk-driver COCs. Finally, degradation and transformation mechanisms for chemicals in the sediment/porewater environment are also discussed.

6.2.1.1 Organic Chemicals

For organic chemicals, the K_d term describes the combined effect of all possible mechanisms affecting distribution between sediment and porewater, including hydrophobic sorption onto organic matter associated with the sediment, electrostatic attractions of oppositely charged ionic

functional groups, and covalent bonding or complexation of ionic organic molecules with reactive surface groups. For non-ionic organic chemicals, which include some of the organic risk-driver contaminants detected in the sediments in the Lockheed West Site (e.g., PCBs, PAHs, and SVOCs), the primary mechanism defining the K_d term is hydrophobic sorption. Therefore, for non-ionic organic chemicals, K_d describes partitioning to the organic matter on the solid surfaces and is approximated as a function of the tendency of the chemical to sorb to organic carbon (K_{oc}) and the fractional organic matter content of the solids (f_{oc}):

$$K_d = (K_{oc} * f_{oc})$$

Where:

- K_{oc} = the partitioning behavior of the chemical between water and the organic matter
- f_{oc} = the mass fraction of organic carbon in the solids

In addition to temperature, several factors can affect equilibrium-partitioning behavior for nonionic organic chemicals:

- **Salinity** – High-salinity environments (e.g., seawater) can cause increased adsorption (decreased solubility and higher observed K_d than predicted at lower salinity). This is an important consideration for the Lockheed West Site because the Site is located in a transition zone between estuarine and marine environments.
- **Cosolvents** – The presence of miscible organic liquids in solution with hydrophobic chemicals can result in increased solubility (and therefore decreased K_d) of the hydrophobic chemical. This effect, however, requires significant amounts of cosolvent chemicals in solution, for which there is no evidence in the marine environment at the Lockheed West Site.
- **Colloids** – Colloids are organic and/or inorganic particles in the system defined by their behavior (tendency to remain dispersed in water, not settle rapidly, and not filter easily) and size (usually 1 nanometer [nm] to 1 micrometer [μm] in diameter). Colloids represent a portion of the particle surface area available for sorption of organic chemicals. Colloidial particles can be mobile in water and can increase the "apparent" concentration of the hydrophobic chemical in the aqueous phase because colloids are less than 1 μm in diameter and would be included in both filtered and unfiltered water samples.
- **Characteristics of natural organic matter** – The amount and nature of the organic matter present in the sediment can also affect the extent of partitioning, making partitioning behavior variable across different environments. Areas with higher amounts

of organic carbon in the sediments will tend to have higher partitioning of organic compounds to the sediments and lower bioavailability to ecological receptors. In addition, some organic compounds can act as surfactants, which can increase the solubilization of hydrophobic compounds in water.

Limited site-specific empirical information, consisting of the porewater data set with paired surface sediment samples, is available to assess sediment porewater partitioning of organic chemicals. The derived K_{oc} values from site-specific data are presented in Appendix A and the site-specific and literature values are presented in Table 6-4.

The site-specific K_{oc} values show that the contaminant partitioning from the porewater to the sediment is strongly in the direction of sorption to the sediment particles. Site-specific derived K_{oc} values for the organic risk-driver contaminants are generally near or above the literature values, indicating a stronger tendency for the contaminants to sorb to the Site sediments than literature data would predict. This strong sorbtion of the contaminants to the Site sediments is potentially due to sediment and water characteristics, such as the ionic strength of the marine water at the Site that increases the sorbtion of the contaminants to the sediment. These results suggest that the likely dominant process for contaminant transport in the system is the movement of sediment particles.

The partitioning tendency for TBT varies from the organic compounds because it is the only definitively ionic organic risk-driver contaminant detected in the sediments at the Site. The partitioning behavior of TBT is strongly affected by pH and the identity of anions in solution that pair with the TBT ion (Arnold et al., 1997). Specifically, for a pH range of 10 to 7 the measured log K_{oc} values are on the order of 4; for the pH range of 7 to 3, they drop to roughly 2, corresponding to two orders of magnitude of partitioning variability across the pH 7 boundary. Measurements of pH for Elliott Bay range from 7.1 to 8.9 (Ecology EIM, 2010) indicating that TBT would be preferentially partitioned more strongly toward the solid phase. TBT in its non-ionic form (not likely present at the Site) is highly hydrophobic, with K_{oc} values on the order of 7. Site-specific derived log K_{oc} values for TBT range from 4.3 to 5.5, which is higher than the log K_{oc} for the pH range of 7 to 10 noted above. This suggests a stronger tendency for TBT to sorb to the sediments at the Lockheed West Site than would be predicted from literature values.

6.2.1.2 Inorganic Chemicals

The fate and transport of inorganic species (e.g., metals) in porewater is defined by the distribution of the species between the aqueous and solid phases. A wide range of mechanisms control the distribution of metals between the aqueous and solid phases. Most commonly these mechanisms include precipitation/dissolution reactions and sorption/ion-exchange processes. Precipitation and dissolution are controlled by the concentration of species present both in solution and as mineral phases. Sorption and ion exchange are controlled by a variety of factors, including electrostatic attraction, covalent bonding, and weak intermolecular attractions such as van der Waals forces.

The distribution of inorganic species between the aqueous and solid phases is controlled by several mechanisms that are a function of the physical, chemical, and biological characteristics of the solid-aqueous system. The characteristics most important for the aqueous solution phase include the following:

- pH,
- Oxidation-reduction potential,
- Presence of competing ions,
- Aqueous complexation reactions, and
- Ionic strength and the specific ions in solution.

The solid phase characteristics of importance include the following:

- Grain size,
- Composition/mineralogy,
- Sorbed organic carbon content and type, and
- Surface characteristics such as charge, coatings, and area.

There are additional factors that cannot easily be assigned solely to the solid or liquid phase, such as temperature and the fugacity of common gases (e.g., oxygen and carbon dioxide).

The aqueous-solid chemistry of the sediment and porewater environment for inorganic chemicals can also be strongly influenced by microbial processes. Microbial oxidation of labile organic carbon, both natural and anthropogenic, frequently depletes dissolved oxygen in porewater,

resulting in chemically reduced conditions and the production of alkalinity. Further, under anaerobic conditions, microbial processes can induce numerous environmentally relevant changes to the chemical environment, such as dissolution of iron and manganese oxide minerals and production of sulfides.

A basic understanding of the fate and transport of inorganic species requires knowledge of the saturation state of aqueous chemical species in the system with respect to minerals that are composed of those species and that may precipitate or dissolve, depending on the saturation state. For a given mineral phase, the solubility product, K_{sp}, defines the equilibrium condition between dissolved ions and the corresponding mineral. Generically, for the dissolution of a hypothetical mineral AbCd:

$$K_{sp} = [A]_b * [C]_d$$

Where:

- [A] and [C] = the concentrations of ions A and C in solution
- b and d = the stoichiometric coefficient of each ion that is present in mineral phase (A_bC_d)

A small K_{sp} favors the precipitation of the mineral from solution, and a high K_{sp} favors the dissolution of the mineral to solution. The solubility product defines the aqueous-solid phase condition under thermodynamic equilibrium. However, many reactions are kinetically limited, and it is relatively common for non-equilibrium conditions to exist in natural aqueous systems.

Sorption and ion-exchange mechanisms for metals can be empirically described by the K_d relationship described above; however, unlike for organic chemicals, the appropriate K_d term is not a function of f_{oc} (although organic matter can also sequester inorganic chemicals, thereby affecting the K_d value).

Derivation of K_d values for the metal risk-driver contaminants (arsenic, copper, lead, and mercury) using site-specific sediment and porewater data is presented in Appendix A. The site-specific and literature K_d values are presented in Table 6-5. The literature values show ranges of one to three orders of magnitude. The wide range in literature K_d values for metals reflects the strong, highly variable geochemical factors, described above, that influence partitioning behavior in environmental systems.

The range of site-specific and literature K_d values indicates that the risk-driver metals are strongly partitioned to the sediments and contaminant migration appears to be driven by sediment particle movement. The site-specific data show that arsenic, copper, and lead are in the middle to upper range of literature values while the range of mercury values for Site sediments is at the low end of the reported range of literature values. Overall, the partitioning results indicate that metals contaminant transport will be primarily driven by sediment particle movement.

6.2.2 Porewater Physical Transport Processes

As discussed above, because the risk-driver contaminants at the Site are strongly partitioned to the sediments, contaminant transport will be primarily driven by sediment movement. Dissolved-phase transport in the porewater and water column will be a minor process for contaminant migration.

Chemicals in porewater are subject to diffusive and advective physical transport processes. These mechanisms are discussed in the following subsections.

6.2.2.1 Diffusive Transport

Diffusion is the movement of particles or dissolved chemical species from higher chemical potential to lower chemical potential (such as is represented by a difference in concentration). This is a spontaneous physical process that requires no additional energy inputs or expenditure. This mechanism is distinguished from advective transport of chemicals in porewater (described in the following section) in that it requires no driving force other than a concentration gradient. Diffusive transport acts on any chemicals in solution and is therefore potentially relevant to all of the chemicals detected in the sediments.

6.2.2.2 Advective Transport

Advective transport of chemicals in the sediment/porewater environment refers to the aggregate movement of dissolved chemicals by flow of porewater through the sediments. Locally, the dominant process is for flow through the sediments to the water column due to groundwater discharge, with a short-term influence of tidal fluctuations. This mechanism can represent a transport process for chemicals in the surface sediment/porewater environment to migrate to the water column.

6.2.3 Degradation/Transformation Processes

A variety of degradation/transformation reactions, including photo-oxidation, photolysis, biodegradation, hydrolysis, dehalogenation, oxidation, and reduction, can occur in aqueous systems.

Of these, the most important processes contributing to degradation of organic risk-driver contaminants in water are photo-oxidation, photolysis, and biodegradation by aquatic microorganisms (Neff, 1982). None of these pathways are considered significant because organic-risk driver chemicals are physically adsorbed to sediment and buried, essentially removing them from exposure to light and the water column. Once buried, the oxic conditions necessary for significant bacterial activity are typically limited to the shallow sediments, though some compounds may undergo biodegradation in anoxic conditions.

While PAHs, PCBs, dioxins, and TBT are susceptible to photolysis, this process is significant only at the surface and upper portions of the water column because ultraviolet light, required to initiate the process, is readily absorbed by water and its intensity rapidly diminishes with depth. Therefore, photolysis is not likely to be a significant degradation pathway, except in intertidal surface sediment where some exposure to light occurs on a seasonal basis.

Biodegradation is unlikely to be a significant process for most types of organic risk-driver contaminants at the Site, as the compounds present are likely to be bound to particles, which would reduce the availability of the chemicals to degrading organisms. The risk-driver contaminants at the Lockheed West Site that can typically be transformed or degraded by microbially mediated processes include TBT, PAHs, and, to a lesser extent, PCBs. Of the risk-driver metals, microbially mediated transformations may occur for mercury, which can be transformed through biological processes to methyl mercury. Methyl mercury is more soluble and volatile than mercury and could be more readily transported, though the potential for volatilization would be limited over most of the Site due to sediment burial and the depth of the overlying surface water.

The biodegradation rate depends on the chemical structure and concentration of the organic compound, the concentration of bacteria responsible for the biodegradation, the availability of organic matter to serve as food, energy sources for bacterial growth, and physical and chemical conditions at the site, such as temperature and oxygen level. The extent to which the organic

compound is bound to particles may also affect the biodegradation rate because the bound organic compounds may be biologically less available for microbial uptake. As shown in Section 6.2.1, the risk-driver contaminants in the sediments at the Lockheed West Site appear to be strongly partitioned to the sediment particles reducing their biological availability and the potential biodegradation rate. In general, PAH compounds can be metabolized by microbes under aerobic conditions. This process is more significant for LPAH compounds than for HPAH compounds. However, under anoxic conditions typically found in fine-grained marine sediment, degradation is extremely slow (Neff, 1982). Oxic conditions are only anticipated in the biologically disturbed layer, which typically ranges from 1 to 15 centimeters in shallower bottom depths of Puget Sound. Therefore, degradation of LPAHs and HPAHs is unlikely in sediment beneath this surface layer.

6.3 SURFACE WATER FATE AND TRANSPORT PROCESSES

From the findings of the *Source Control Information and Data Gap Report* and *Source Control Evaluation Report* and the discussion in Sections 6.1 and 6.2, the dominant contaminant transport process for the Site is the movement of sediment particles. Surface water transport processes are likely to have only a small influence on contaminant fate and transport at the Site.

Chemicals in surface water are sorbed to suspended solids and, to a lesser extent, in the dissolved phase. Fate and transport processes for chemicals in surface water (including movement of surface water and suspended solids; partitioning of chemicals between water, air, and suspended solids; and degradation/transformation reactions) are described in the following subsections.

6.3.1 Physical Transport of Chemicals in Surface Water

Advection is the primary mechanism for transport of surface water and its load of particle-bound and dissolved chemicals.

Off-site in-water sources including other contaminated sediment sites represent the primary concern for this pathway. As noted earlier in Section 5.0 and earlier in this section, the Site likely receives in-water contamination from the Lower Duwamish Waterway, the West Waterway, and Elliott Bay. This in-water contamination, most likely represents contamination sorbed to suspended sediments or bedload sediments.

It is likely that contaminants dissolved in the surface water are a minor contributor to Site sediment. Significant point source discharges (e.g., CSOs, industrial wastewater discharge locations) and contaminated groundwater are not thought to represent a significant source of contamination for the Lockheed West Site.

6.3.2 Physiochemical and Biological Attenuation Processes in Surface Water

Once chemicals enter surface water, several major physical, chemical, and biological processes can result in transfer of chemicals between abiotic media (water, suspended solids, sediment, and air) or degradation/transformation of chemicals. These processes include sorption, precipitation, volatilization, abiotic degradation (chemical reaction or photolysis), and biodegradation. With the exception of volatilization, these processes also generally pertain to porewater and sediment interactions and are discussed in Section 6.2.

Volatilization, the transfer of chemicals dissolved in surface water to the atmosphere, is a process that transports chemicals out of the water column. Volatilization is an important factor for small organic molecules, such as VOCs and some forms of mercury (e.g., elemental mercury and methylmercury) and lead (e.g., tetraethyllead and tetramethyllead). However, since the risk-driver contaminants in the sediment appear to be strongly sorbed to the sediment particles and are generally nonvolatile, volatilization is not expected to be a significant process at the Lockheed West Site.

Other processes, including photo-oxidation, biodegradation, hydrolysis, dehalogenation, oxidation, and reduction (described in Section 6.2.3), can occur in the surface water. As described earlier, these processes are limited by the conditions under which they will occur and the strong partitioning of the risk-driver contaminants to the sediments reduces the importance of these processes for the Lockheed West Site sediments. Surface water attenuation processes are expected to be minor for the Site sediments.

6.4 BIOTA-RELATED FATE AND TRANSPORT PROCESSES

The uptake of sediment contaminants to biota is an important consideration for the baseline *ERA* and *HHRA*. For these risk assessments, the uptake of contaminants was modeled by biota-sediment accumulation factors (BSAFs). The BSAFs evaluated the contaminant concentrations

found in clam tissue to the concentrations detected in the Site sediments. This approach captures all of the pathways for the contaminants from the sediment to Site organisms for the purposes of evaluating the risk to Site biota. Although not used in the risk assessments, the discussion below is included to describe the details of the sediment-to-tissue pathways.

A number of processes govern how organisms living in the Site sediment area are exposed to chemicals and how chemicals are transformed, excreted, or stored in tissue. Organisms living in the sediment in the Lockheed West Site vicinity take up chemicals through physically (e.g., diffusion), chemically, and biologically mediated processes, including transfer of waterborne chemicals across gill structures or other tissues, consumption of prey, or ingestion of sediment. Organisms can modify the chemical burden in their tissues through growth, reproduction, excretion, metabolic transformation, or sequestration. Some chemicals are transferred among organisms through trophic interactions, resulting in accumulation of some chemicals at higher trophic levels.

Several of the chemicals (e.g., PCBs and PAHs) that have been measured in invertebrates and fish in the general Site vicinity are hydrophobic and likely to be highly associated with organic materials (i.e., dissolved or particulate carbon in the surface water, porewater, and sediment). However, some metals (e.g., lead and zinc) also tend to associate with organic and inorganic solids because the geochemical properties (e.g., ionic charge) governing their behavior tend to promote sorption.

Once released to the aquatic environment, chemicals enter the food web in a number of ways; the process is not sequential in that all trophic levels can interact with abiotic media. The behavior of chemicals within an aquatic food web is briefly described below.

Primary producers such as phytoplankton and plants take up chemicals mainly through diffusion from the water to which they are exposed, although the lipid content of phytoplankton also serves as a substrate for the partitioning and binding of organic compounds that may be in a dissolved state or bound to colloidal organic carbon. Metabolic byproducts from phytoplankton contribute to the colloidal material in the water column, which can also bind with chemicals dissolved in the water column. These colloidal materials can be directly utilized by bacteria,

other phytoplankton, and zooplankton; this process serves as an additional chemical uptake and transfer mechanism for recycling chemicals within the water column food chain.

Zooplankton prey upon phytoplankton and other zooplankton, further recycling chemicals in the water column. More complex aquatic organisms (e.g., invertebrates and fishes) can take up dissolved or colloidally bound chemicals in surface water and porewater across gill membranes, skin, and other permeable tissue, such as the mantle in clams (shells, exoskeletons, and scales are less permeable). Sediment surfaces may be coated with bacteria and bacterial slimes, natural organic polymers, and other amorphous organic molecules that serve as binding sites.

Once sediment or prey is ingested by invertebrates and fishes, chemical absorption across gut membranes is affected by the size of the molecule (larger molecules being more difficult to transfer across membranes), concentration gradients between gut content and surrounding tissues, acidity of the gut, and other physical/chemical conditions in the gut. Organisms can react with absorbed chemicals through various metabolic processes that result in a change in the chemical structure and properties. Absorbed metals that are not excreted may end up stored in calcium carbonate matrices (invertebrates) or bone (vertebrates); these storage sites tend to reduce the reactivity of the metal. Organic compounds that are not metabolized tend to be stored in organs or fatty tissues, including gametes. These stores can be released within the aquatic and terrestrial food webs when these organisms are ingested by others, upon their death and decomposition, or by transfer to their offspring.

6.5 SUMMARY

Most of the risk-driver contaminants in the sediments at the Lockheed West Site partition strongly to sediment particles. The Site represents a net depositional area characterized by a low sedimentation rate. In the vicinity of the Site, there is evidence of suspended and bedload sediment transport that carries low-level contamination for select COCs above Lockheed West RBTCs and background concentrations. The sediment stability analysis for the Site indicates that the bed sediments are not likely to be moved by wave action and the bathymetry survey supports the conclusion that the Site sediments are stable. The potential for contaminant migration off-site through the migration of sediment particles is low in part because the Site is a net depositional area.

Table 6-1.
Wind-Wave Height and Peak Period Summary
Todd Shipyard Sediment Operable Unit

Return Period	Wave Height (Feet)	Peak Period (Seconds)
5-year	3.56	3.96
25 year	4.38	4.34
Source: Floyd|Snyder and CHE, 2007.		

Table 6-2.
Average Physical Properties of
Lockheed West Site Surface Sediments (0- to 1-foot depth interval)

Parameter	Value	Units
Specific gravity	1.5	NA
Median grain size	0.1	Millimeters
Note: NA = Not Applicable		

Table 6-3.
Near-Bottom, Maximum Velocity
and Shear Stress Due To Extreme Storm Events at Lockheed West Site

Return Period Maximum Near-Bottom	Velocity (meters/second)	Maximum Near-Bottom Shear Stress (Pa)
5-year	9.25×10^{-3}	0.124
25-year	1.5×10^{-2}	0.266
Note: Pa = Pascal (equivalent of Newton per square meter).		

Table 6-4.
Site-Specific Calculated and Literature Organic Partitioning Coefficients

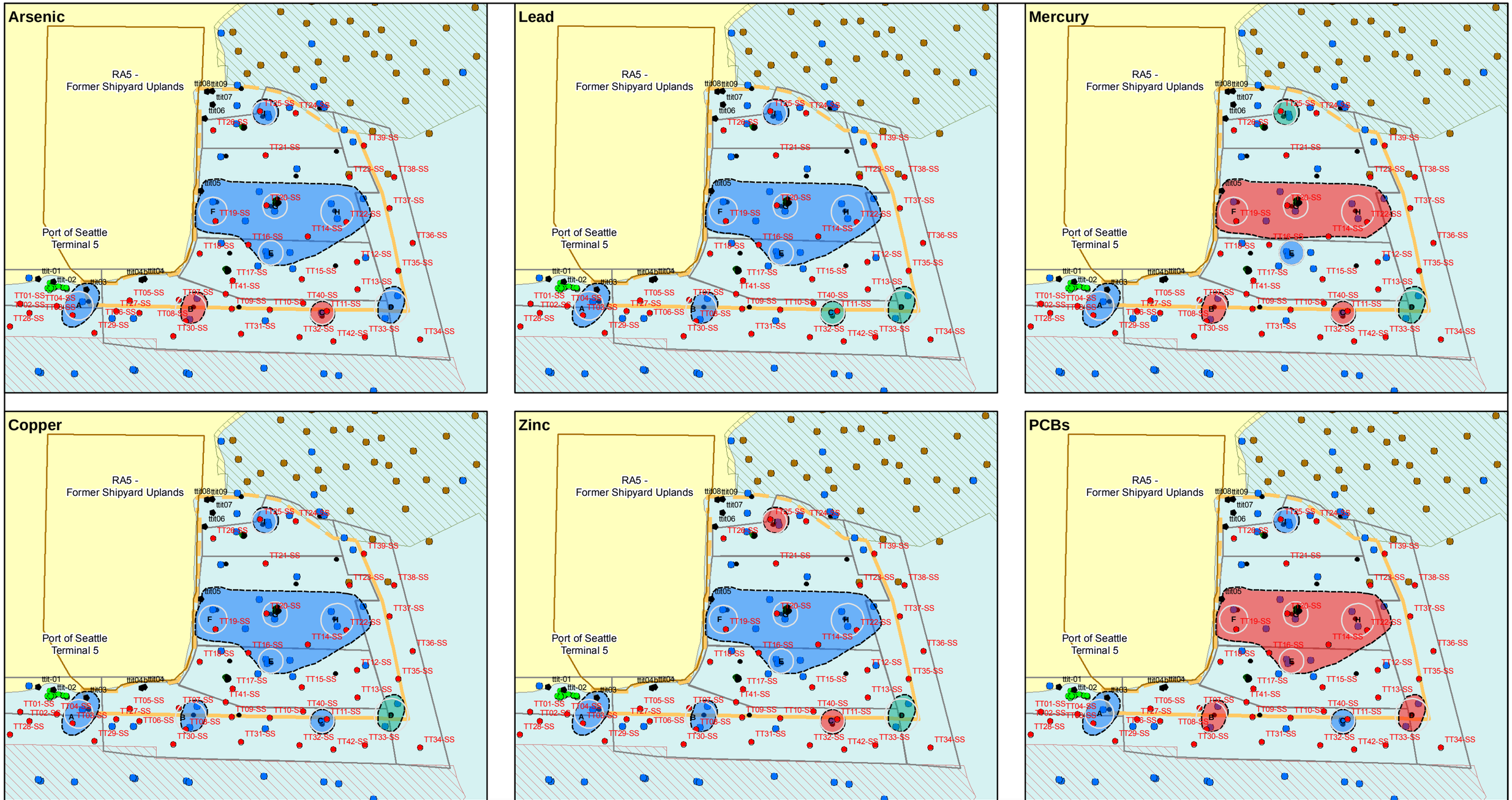
Parameter	Calculated Range(Log K_{oc})	Literature Value (Log K_{oc})[1/]
PCBs	5.22 – 5.72	3.92 – 5.54
2-Methylnaphthalene	4.34 – 5.03	3.39
Acenaphthene	4.41 – 5.73	3.70
Acenaphthylene	4.49 – 5.29	NA
Anthracene	4.83 – 5.48	4.21
Benzo(a)anthracene	5.08 – 5.84	5.25
Benzo(a)pyrene	4.81– 5.33	5.77
Benzo(b)fluoranthene	4.91 – 5.41	5.78
Benzo(g,h,i)perylene	4.86 – 5.31	NA
Benzo(k)fluoranthene	4.61 – 5.22	5.77
Benzofluoranthenes (total)	4.81– 5.33	5.77
Chrysene	5.04 – 5.70	5.26
Fluoranthene	5.11 – 5.86	4.74
Fluorene	4.78 – 5.68	3.96
Indeno(1,2,3-cd)pyrene	4.86 – 5.36	6.29
Naphthalene	4.49 – 5.39	3.19
Phenanthrene	5.25 – 5.84	NA
Pyrene	5.10 – 5.43	4.74

Notes:
1/ EPA, 2010a
K_{oc} = organic carbon partitioning coefficient
PCBs = polychlorinated biphenyls

Table 6-5.
Site-Specific Calculated and Literature K_ds for Risk-Driver Metals

Parameter	Calculated Range(Log K_d)	Literature Value (Log K_d)[1/]
Arsenic	3.13 – 3.51	1.6-4.3-
Copper	3.62 – 5.20	0.7 – 6.2
Lead	4.01 – 4.47	2.0 – 7.0
Mercury	3.27 – 4.05	3.8 – 6.0

Notes:
1/ EPA, 2005a
K_d = solid/water distribution coefficient.



Legend

1998 and Earlier Sampling Locations
- Surface Grab
- Puget Sound Resources Remedial Investigation Station Points

2003 Sampling Locations
- Surface Grab

2007 Sampling Locations
- Surface Grabs
- Intertidal Sampling Location
- Clam Sample Locations

- Former Lockheed Martin Property and Lease Area Boundary
- Approximate Site Boundary (site boundaries will be finalized in the Record of Decision)
- Survey Sub Areas (Based on Historical Site Use)
- Pacific Sound Resources Marine Sediment Unit (approximate)
- Western Waterway OU (approximate)
- RA5 - Former Shipyard Uplands

Concentration Trend Over Time (Approximately from 1985/1989 to 2003/2007)
- Increasing
- Decreasing
- Relatively Unchanged
- Surface Sample Station Clusters

Notes:
OU = Operable Unit
PCBs = polychlorinated biphenyls

0 125 250 500 Feet

Figure 6-1
Surface Sampling Concentration Trends

Lockheed West Seattle Superfund Site
Seattle, WA

TETRA TECH

Z:\Pdrive\Projects_2006\Lockheed\maps\RIFS_Report\Figure_6-1_concentrations.mxd

SECTION 7

Summary of the Baseline Human Health and Ecological Risk Assessments

This section presents summaries of the baseline *HHRA* and *ERA* for the Lockheed West Site. One of the objectives of the RI for the Site is to assess human and ecological risk under baseline conditions and to identify COCs that may pose unacceptable risk. Baseline conditions are defined as the conditions at the site (i.e., levels of contamination and types of exposures) as they presently exist in the absence of any remediation. The human health and ecological risk assessments for the Lockheed West Site were performed consistent with CERCLA guidance (EPA, 1988) and the requirements of the Statement of Work as defined in the Administrative Settlement Agreement and Order on Consent (EPA Docket No. CERCLA-10-2006-0321).

The objectives of the risk assessments are to identify chemical contaminants, human and ecological receptors, and the pathways by which they may be exposed that could result in unacceptable risks to human health or the environment. The risk assessments focus on those contaminants that are predicted to represent the greatest contribution to risks at the Site. Under CERCLA, risk assessment is one of several considerations used by risk managers to aid in decision-making regarding potential risks and the means to reduce unacceptable levels of risk. The results of the risk assessments are used in the FS to develop preliminary remediation goals (PRGs) for the Lockheed West Site that satisfy RAOs related to protecting human health and the environment

During development of the *RI/FS W ork P lan,* Lockheed Martin worked with EPA and stakeholders to develop the methods and assumptions used in the risk assessments. The risk assessments have been developed to provide a conservative assessment of risks associated with contaminants present at the Site. The methods and inputs for the risk assessments reflect

numerous discussions, directives, and agreements with stakeholders, including EPA and the Muckleshoot and Suquamish tribes. The methodologies and detailed findings of the risk assessments can be found in the *ERA* and *HHRA*, which are included as Appendices B and C, respectively.

The approach to both the human health and ecological risk assessments for the Lockheed West Site was to use a combination of site-specific sediment chemistry data, exposure scenarios developed for the LDW (located upstream from the Lockheed West Site), and EPA guidance on literature values to estimate risks to human and ecological receptors. The similarities in aquatic habitat and types of resources, including seafood, between the Lockheed West Site and the LDW, and the possible future human uses of the Lockheed West Site, were the basis for applying the technical approach and specific exposure and toxicity parameters from the LDW to the Lockheed West Site human health and ecological risk assessments. Use of the LDW exposure scenarios and all inherent assumptions and exposure parameters is protective of human populations and ecological receptors such as fish and wildlife that may use the Site at present as well as in the future.

7.1 HUMAN HEALTH RISK ASSESSMENT

The human health risk assessment was performed following four steps per EPA (1989) guidance. Application of each of these steps is briefly described below; results of risk estimates are tabulated in the Risk Characterization (Section 7.1.4).

7.1.1 Data Evaluation

Site data consisted of the surface sediment chemistry data collected in 2007. Sediment samples were analyzed for metals, SVOCs, PAHs, organochlorine pesticides, and PCBs. The sediment data on organochlorine pesticides, such as DDT, were found to be highly uncertain due to unavoidable interferences associated with the presence of PCBs during the chemical analyses; for that reason, DDT data were qualified as tentative for unconfirmed identification. Consistent with the EPA-approved *RI/FS Work Plan*, data on dioxins and furan were not collected because dioxins and furans are not believed to represent Site-related contaminants. However, at the request of EPA they were identified as COCs in the risk assessment based on their presumed presence at the site. However, as discussed in Section 4.7, limited dioxin/furan data were

collected from the Site as part of the clam reconnaissance survey. Those results confirmed their presence at low concentration levels at the Site.

7.1.2 Exposure Assessment

The exposure assessment presents exposure pathways, results of screening and selection of COPCs, and the exposure parameters used to quantify and characterize human health risks.

7.1.2.1 Conceptual Site Model and Exposure Pathways

The human health conceptual site model describes scenarios in which people could be exposed to contaminants associated with sediment at the Lockheed West Site, and is depicted in Figure 7-1. The exposure scenarios were selected to be those with potentially the highest risks, based on the exposure scenarios evaluated in the LDW HHRA (Windward, 2007a) that could be applicable to conditions at the Lockheed West Site. Five exposure scenarios were identified as reasonable maximum exposure (RME) scenarios: child beach play, tribal clamming (i.e., collection of clams by tribal members), tribal netfishing, and the consumption of seafood (including clams) by tribal adults and children. The five RME scenarios were approved for the Site by EPA in the *RI/FS Work Plan*. For the seafood consumption scenarios, the exposure pathway of concern is ingestion of seafood that contains Site-related sediment contaminants in their tissue. For direct contact scenarios, exposures consist of direct contact with Site sediment contaminants followed by absorption across the skin and by inadvertent ingestion of sediment particles. This summary focuses on the five RME scenarios; details on additional non-RME scenarios are presented in the Lockheed West *HHRA*.

7.1.2.2 Screening and Evaluation of Chemicals of Potential Concern

Risk-based screening was performed using EPA guidance to identify COPCs, which were then evaluated for potential health risks to humans in the Risk Characterization. For exposures related to direct contact with sediment, the maximum concentrations of contaminants detected in sediment were screened against risk-based concentrations (RBCs) developed in the LDW HHRA (Windward, 2007a) to account for tribal exposures.

Sediment screening criteria for the seafood consumption exposure pathway were also based on the LDW HHRA and developed as RBCs based on acceptable levels in seafood, adjusted to

account for tribal exposures. For the seafood consumption RME scenario, a total of 14 COPCs were identified for estimating risks (Table 7-1), consisting of 7 metals plus TBT, 5 organic compounds (cPAHs, two individual PAHs, pentachlorophenol, and total PCBs), and 2 organochlorine pesticides (total DDTs and total chlordanes). For both the seafood consumption and direct contact scenarios, dioxins and furans are identified as COPCs based on their presumed presence in Site sediment and seafood, although representative data were not collected on them in sediments.

For direct sediment RME exposure scenarios (i.e., netfishing, beach play, and clamming), a total of seven chemicals were identified as COPCs for estimating risk (Table 7-1), consisting of five metals and two groups of organic compounds (cPAHs and total PCBs). For both the seafood consumption and direct contact scenarios, dioxins and furans are identified as COPCs based on their presumed presence in Site sediment and seafood, although representative data were not collected on dioxins and furans in sediments.

7.1.2.3 Quantifying Exposures

The Exposure Assessment quantified the amount of contaminants that a person may be exposed to, either by ingestion of contaminants in sediment or seafood, or by dermal absorption of contaminants from sediment adhering to the skin. Exposures to COPCs at the Site were calculated using concentrations in sediment and seafood, EPA equations, and exposure parameters from the LDW HHRA, such as time spent at the intertidal sediment area during beach play, time spent in netfishing, and the amount of seafood ingested, including clams, crabs, and fish.

EPA proposed the use of Tulalip seafood consumption rates, as specified in the EPA tribal seafood consumption framework (EPA, 2007a), to characterize the adult tribal RME and child tribal seafood consumption scenarios. EPA consulted with the Muckleshoot and Suquamish Tribes, and the outcome of this consultation was the use of the Tulalip ingestion rates, realizing that risk-based cleanup levels were not attainable because of background considerations. In addition to the RME scenario, the Suquamish Tribe specifically requested inclusion of a Suquamish tribal scenario as relevant to Suquamish tribal members. The Tulalip consumption rates were used for the RME scenario, whereas analysis of adult Suquamish seafood

consumption was included as a high-end exposure scenario that depicts upper bound risks for tribal seafood consumers.

The total consumption rate of non-anadromous seafood (i.e., seafood exclusive of fish such as salmon that live in salt water and migrate upstream into freshwater to spawn) for the adult tribal RME scenario was 97.5 grams of seafood per day (three meals per week, assuming a meal weighs 227 grams, which is about 8 ounces); the total consumption rate of non-anadromous seafood for the Suquamish scenario was 583.5 grams of seafood per day (2.6 meals per day, assuming a meal weighs 227 grams). Contaminant exposures associated with consumption of migratory anadromous species (i.e., salmon) were not included in the *HHRA,* because bioaccumulative chemicals found in adult salmon tissue are largely the result of exposures from the Pacific Ocean and Puget Sound, where they spend most of their life, rather than from the Lockheed West Site. The contribution to adult body burdens from exposures in the Elliott Bay and West Waterway areas of the Lockheed West Site is likely to be insignificant, as has been shown for salmon in the much larger LDW site. Therefore, salmon consumption was not included in this risk assessment, consistent with the HHRA for the LDW site.

Exposure point concentration (EPC) is either the maximum concentration or the 95 percent upper confidence limit on the mean concentration of a COPC in sediment or tissue, and is intended to represent a long-term exposure concentration. For beach play and clamming exposures, sediment EPCs were derived for intertidal sediment; for netfishing exposures, EPCs were derived for subtidal plus intertidal sediment.

Consistent with the LDW HHRA, the exposure frequency for the beach play scenario was set at 65 days per year. Two clamming scenarios were evaluated: a tribal clamming RME scenario of 120 days of clamming per year and a tribal clamming scenario of 183 days per year, which was included at the request of EPA and the tribes to represent a high-end clamming frequency. The clamming scenarios used contaminant concentration data from all intertidal areas at the Site, regardless of whether clams may be present or whether habitat may be suitable for clams. Based on results of the RI, it appears that the currently suitable habitat for clams is limited and the occurrence of clam species that are commonly harvested is low (see Section 4.3); therefore, the

clamming scenarios are likely conservative. The netfishing scenario was based on information on tribal netfishing practices that was used in the LDW HHRA (Windward, 2007a).

Seafood tissue concentrations of COPCs were estimated from the sediment concentrations; tissue data were not collected from the Site for use in estimating tissue EPCs. Modeling was performed using BSAFs and regression equations that relate tissue concentrations of chemicals to the concentrations in sediment. The BSAFs were single numerical values taken from public databases and the scientific literature; regression equations were derived from a food-web model for PCBs and from data collected from the LDW (Windward, 2008). Alternative BSAFs for metals were also developed from clam data collected at the Lockheed West Site and from site-wide data collected from the LDW site for other seafood tissues (see Appendix E of the Lockheed West *HHRA*). For the seafood consumption scenario, COPCs in seven seafood categories were quantified, following precedent in the LDW HHRA: pelagic fish (i.e., fish that primarily live and feed in the water column), fillets of benthic fish (i.e., fish that primarily live and feed along the bottom or within the sediments), whole bodies of benthic fish, edible meat of crabs, and whole bodies of crabs, clams, and mussels.

7.1.3 Toxicity Assessment

The Toxicity Assessment identified appropriate toxicity values for all COPCs, which consisted of the cancer slope factor (CSFs) for evaluating carcinogenic risks and reference doses (RfDs) for evaluating effects other than cancer. Toxicity values were taken from EPA sources. The CSFs provide a health-protective means to evaluate risks because they represent upper bound estimates of carcinogenic potency. Non-cancer RfDs are typically based on the most sensitive endpoint and population for which adequate data are available, and include uncertainty and modifying factors to account for sensitive sub-populations or other limitations of the toxicity data. The toxicity values are used with the EPCs identified in the Exposure Assessment to quantify the risk estimates.

7.1.4 Risk Characterization and Uncertainty Analysis

For the Risk Characterization, carcinogenic risks and non-carcinogenic hazards were evaluated separately. Carcinogenic risk estimates were calculated by multiplying the estimated chemical intake into the body by the CSF. Cancer risk estimates were compared with the EPA acceptable

risk range of 10^{-6} to 10^{-4} established in the NCP for Superfund sites (40 Code of Federal Regulations [CFR] 300). Contaminants with non-carcinogenic health effects are generally not toxic below a certain threshold, which is represented by the RfD. The potential for non-carcinogenic health effects is quantified as the ratio of the estimated contaminant intake to the RfD, expressed as a hazard quotient (HQ). Exposures resulting in an HQ less than or equal to 1 are unlikely to result in non-cancer adverse health effects. The effect-specific hazard index (HI) is an expression of the additivity of non-carcinogenic health effects. An effect-specific HI can be calculated by summing HQs for contaminants with similar toxicological effects (e.g., immunotoxicity). If the sum of all HQs for a given scenario was less than 1, no effect-specific HIs were calculated because they would also not exceed 1. Effect-specific HIs were calculated for scenarios when the sum of all HQs was greater than 1.

Estimated excess cancer risks were higher for the seafood consumption scenarios than the direct sediment exposure scenarios. Estimated cancer risks for the RME adult and child tribal seafood consumption scenarios for each COPC are presented in Table 7-1. For the adult tribal RME seafood consumption scenario, the total cancer risk for all carcinogenic chemicals was 9×10^{-3} (i.e., an additional nine in one thousand chance of developing cancer), with equal contributions to the risk estimates from inorganic arsenic, PCBs, and cPAH (i.e., each contributed 3×10^{-3}). Use of a BSAF for arsenic developed from clam and sediment data collected from the Lockheed West Site results in a higher estimated arsenic cancer risks for the adult tribal RME seafood consumption scenario, up to 10^{-2}, and total cancer risks > 10^{-2}. For the Suquamish adult tribal seafood consumption scenario, the cumulative risk for all carcinogenic chemicals was 5×10^{-2}, and the tribal child cumulative risk for all carcinogenic chemicals was 4×10^{-3}. These cancer risk levels are more than 5 times higher than the adult tribal RME risks, reflecting a much higher seafood consumption rate (almost three meals per day) for the Suquamish data.

For non-cancer hazards under the RME seafood consumption scenarios, PCBs and TBT accounted for greater than 90 percent of the hazards for both the child and adult tribal RME seafood consumption scenarios (Table 7-1).

Excess cancer risks for the direct sediment exposure scenarios were much lower than those for the seafood consumption scenarios. All excess cancer risk estimates for RME direct sediment

exposure scenarios were less than or equal to 1×10^{-4} (Table 7-1). Excess cancer risk estimates for the non-RME high end clamming exposure scenarios were about twice those estimated for the RME scenario. For non-cancer risks, the HI for the child beach play scenario was 2.6, with arsenic contributing an HQ of 1.8; HIs for the remaining direct sediment exposure scenarios were less than 1.

As part of the characterization of human health risks, several uncertainties were examined that could affect interpretation or management of risks. Of primary importance to this risk characterization, all exposure scenarios that were considered relevant to the Lockheed West Site conditions were taken directly from or modified from the LDW HHRA whereas the sediment chemistry data are specific to the Lockheed West Site. The use of exposure parameters that are not site-specific entails a high level of uncertainty regarding the specificity of the risk estimates to the actual Site conditions. A second major source of uncertainty was the use of modeling to determine the concentrations of contaminants in seafood, primarily because of the limited availability of modeling parameters and the uncertainty over their application to the conditions of the Site.

Another source of uncertainty is the use of the Tulalip survey seafood ingestion rates to develop the screening criteria for identifying all COPCs. The Suquamish survey seafood ingestion rates are higher than the Tulalip survey ingestion rates, and the use of the Suquamish survey seafood ingestion rates to develop screening criteria would result in lower sediment screening criteria, which could result in the selection of additional chemicals as COPCs and additional contributions to risk estimates for the Suquamish seafood consumption scenario. However, the extent of contribution of any additional COPCs to the total health risk in the Suquamish seafood consumption scenario would be so low as to not affect the total cancer risk estimate for that scenario. For example, the total cancer risk estimate for the Suquamish seafood consumption scenario is 5×10^{-2}, which is driven mostly by arsenic and cPAHs in sediment, each contributing about one-half of the estimated cancer risk. Total PCBs contribute about one-fifth to this risk estimate and pentachlorophenol contributes about 0.02 percent. Any additional COPCs identified by using lower screening criteria would contribute less than 0.02 percent to the total cancer risk.

Because these additional COPCs contribute a relatively small amount to the total cancer risk estimates compared to the present risk drivers, they would not add to the list of risk-driver contaminants for the Suquamish seafood consumption scenario. In addition, the use of lower screening criteria would not add risk drivers to the tribal RME seafood consumption scenario, and they would not change the identification of COCs for the tribal RME seafood consumption scenario or change risk-based cleanup levels that may be calculated for RME COCs.

The final step of the risk characterization is to identify COCs and risk drivers for the Site, with risk drivers defined as the COCs contributing the majority of the site risks. The COCs and risk drivers for both human health and ecological exposures are identified in Section 7.3 following the summary of the *ERA*.

7.2 ECOLOGICAL RISK ASSESSMENT

Similar to the approach for the *HHRA* discussed above, and consistent with the EPA-approved *RI/FS Work Plan*, the approach to the *ERA* for the Lockheed West Site used a combination of site-specific information (such as surface sediment data and identification of intertidal habitat at the Site) and ecological parameters from the nearby LDW (Windward, 2007b). The *ERA* focused on the ecological receptors that were identified as having the highest risks at the LDW and that might use the Lockheed West Site. Exposure parameter values were used from the LDW ERA, regardless of differences in size of the exposure area at the Lockheed West Site or availability of ecological habitat.

The baseline *ERA* presents risk estimates for benthic invertebrate, fish, and bird species that may be exposed to contaminants in Site sediment and in the food chain. The baseline *ERA* followed EPA guidance and consists of separate sections on Problem Formulation, Exposure Assessment, Effects Assessment, and Risk Characterization/Uncertainty Analysis, each of which is briefly summarized below.

7.2.1 Problem Formulation

The Problem Formulation step establishes the ecological scope of the assessment. The *ERA* focused on receptor species that have the highest potential exposures to site-related chemicals and that serve to represent other species or groups of organisms that may also be exposed. These

receptors of concern (ROCs) were selected based on the site habitat characteristics and the pathways of exposure to Site-related chemicals. Ecological receptors of concern and pathways of exposure were identified in the conceptual site model as the following (Figure 7-2):

- Benthic invertebrate community, including clams – direct contact and ingestion exposure to subtidal and intertidal sediment;
- Crabs – exposure to ingested prey and direct contact and ingestion exposure to subtidal and intertidal sediment;
- Fish (English sole, Pacific staghorn sculpin) – exposure of higher trophic organisms to ingested prey and direct contact and ingestion exposure to subtidal and intertidal sediment; and
- Birds (spotted sandpiper) – exposure to ingested prey and ingestion exposure to intertidal sediment.

Other potential receptors, such as mammals or piscivorous birds, were not selected as ROCs due to their limited exposures at the Site. In addition to selecting ROCs on which to focus the assessment, the Problem Formulation selected a list of COPCs through a conservative screening process that served to focus the assessment on contaminants likely to pose an ecological risk. The Site data consist of surface sediment contaminant concentrations collected in 2007 from 42 subtidal and 9 intertidal stations in both the West Waterway and Elliott Bay areas of the Site, and sediment porewater TBT concentrations from a limited number of stations.

For the benthic community, COPCs were identified by comparing sediment contaminant concentrations at each intertidal and subtidal sediment station with sediment quality criteria. For fish and crabs, COPCs were identified as those bioaccumulative contaminants with concentrations in sediment that exceeded risk-based sediment bioaccumulation criteria. For sandpiper, COPCs were identified based on exceedance of risk-based concentrations in sediment.

The selected COPCs consisted of 11 metals, tributyltin, PAHs, PCBs, several other SVOCs, and organochlorine pesticides (e.g., DDT). All of the organochlorine pesticides that were detected were qualified as estimated concentrations and only tentatively identified as present in the sediment sample.

The Problem Formulation also identified the characteristics of the ROCs that are considered of importance in evaluating risks to populations, such as growth, survival, and reproduction, and identified the means to measure these effects, called the assessment and measurement endpoints. The *ERA* focused on endpoints that integrate an exposure to an individual and on those effects that could affect aquatic populations at the site.

7.2.2 Exposure Assessment

The Exposure Assessment estimated the potential exposure of each ROC to the COPCs identified in the Problem Formulation, using exposure pathways and parameters from the ERA for the LDW (Windward, 2007b). Exposure to surface water in Elliott Bay or the West Waterway at the Lockheed West Site was not included in the ERA, as defined in the EPA-approved *RI/FS Work Plan*.

The quantitation of exposures to each ecological ROC depends on the types of toxic effects data that are used to assess risks for the ROC. For the benthic invertebrate community, exposures to COPCs were assessed by quantifying contaminant concentrations at each of the 51 surface sediment sample locations. For crabs and benthic invertebrates exposed to TBT, effects were evaluated using toxicity data based on tissue concentrations, and exposures were evaluated by quantifying concentrations in their tissues. Exposure of benthic gastropods to TBT was also evaluated with sediment porewater data from the Site.

For fish, two scenarios were used for the evaluation of exposures based on the following two types of effects data: 1) estimated concentrations of chemicals in fish tissue for those chemicals evaluated using toxicity data related to whole body tissue concentrations, and 2) estimated concentrations in prey that fish consume for contaminants with toxicity data related to dietary exposures. Fish dietary prey consisted of benthic invertebrates for the English sole, and benthic invertebrates, crab, and fish for the Pacific staghorn sculpin.

For the spotted sandpiper, because toxicity effects data are related to the estimated intake or dose of a contaminant, exposures were evaluated by quantifying intake of contaminants present in intertidal sediment that they may ingest and in tissue of intertidal benthic invertebrates that they consume as prey.

Concentrations of COPCs in fish and crab tissues and in prey for fish, crabs, and spotted sandpiper were modeled from concentrations in Site sediments, using the same modeling methods as used for the *HHRA.*

7.2.3 Effects Assessment

The Effects Assessment identified the potential adverse effects to ecological ROCs from exposures to the COPCs in Site sediment. For the benthic invertebrate community, potential adverse effects for most COPCs were quantified using chemical criteria in the Sediment Management Standards: the SQS, which corresponds to a sediment quality that will result in no adverse effects to biological resources, and the CSL, which corresponds to a sediment quality that will result in minor adverse effects (WAC 173-204). For COPCs without Washington State sediment management criteria, toxicologically based guidelines from the DMMP or toxicity information from the literature were used. The evaluation of TBT risks to benthic invertebrates used effects data related to tissue concentrations.

For crabs and fish, effects data were identified as COPC concentrations in their tissue or tissue of prey items; for sandpiper, effects data were identified as doses. All effects data were selected for the most sensitive endpoint of survival, growth, or reproduction (EPA, 1997a). Both no-observed-adverse-effect level (NOAEL) and lowest-observed-adverse-effect level (LOAEL) values were identified as toxicity reference values (TRVs), which were used with exposure data to characterize risks to crabs, fish, and sandpipers.

7.2.4 Risk Characterization and Uncertainty Analysis

The exposure and effects data were compared in the Risk Characterization to assess the potential for sediment-associated COPCs to cause adverse effects to the ROCs. The results of the risk characterization are summarized for each of the ROCs in the following:

- **Benthic Invertebrate Community** – The potential for adverse effects to benthic invertebrates differed between intertidal and subtidal sediments. Sediment concentrations of contaminants exceeded CSL or similar effects-based sediment guidelines in 67 percent of intertidal sediment locations (Table 7-2) and 48 percent of subtidal sediment locations (Table 7-3), primarily due to arsenic, copper, and mercury. For intertidal sediments, about 11 percent of the locations have no potential for adverse effects to benthic

invertebrates (Table 7-2). The remaining 22 percent of the intertidal sediment locations with concentrations between the low and high sediment criteria have less certain risks. Very low risks were predicted for exposure of benthic invertebrates to PAHs, PCBs, and other organic chemicals in intertidal sediments due to low concentrations.

For subtidal sediments (Table 7-3), about 24 percent of the sediment locations would have no potential for adverse effects to benthic invertebrates. Risk to gastropods from TBT exposure were low based on the tissue NOAEL-HQ less than 1, but were higher based on TBT concentrations in sediment porewater.

- **Crabs –** Risk to crabs from exposure to TBT in Site sediments were estimated to be high, with an HQ greater than 200 based on the NOAEL (Table 7-4). The risk of actual effects is uncertain because of the lack of a LOAEL and because exposure was based on modeling of TBT in crab tissue, since tissue data were not available. Risks from total PCBs were estimated as low.
- **Fish –** For fish, the highest risks were found for copper and TBT to English sole, with LOAEL-based HQs of 18 for both COPCs (Table 7-4). Low risks were found for PCBs, with LOAEL-based HQs ranging from 1 to 6. Copper was estimated to present risks to English sole and sculpin through dietary exposure (LOAEL-based HQs of 18 and 14, respectively).
- **Birds** – For sandpiper (Table 7-5), the highest risks were found for intertidal lead, with a LOAEL-based HQ of 14, with lesser but potential risks from chromium and copper (LOAEL HQs of 1 and 3, respectively); PCBs were not found to present a risk to sandpipers. Risks to spotted sandpiper from dietary exposure to TBT and organic compounds were found to be very low.

In summary, ecological risks were estimated to be above regulatory thresholds for select chemical contaminants for the benthic invertebrate community, crab, fish, and sandpiper. Uncertainties in the risk estimates are primarily related to the use of modeling to estimate exposures of crab, fish, and sandpiper prey to contaminants present in Site sediment; and the reliance on exposure assumptions from the LDW, whereas the Lockheed West Site presents smaller areas of sediment for exposures and smaller areas for fish and crab to contact Site sediments and take up Site-related chemicals.

7.3 SUMMARY OF CONTAMINANTS OF CONCERN

Contaminants of concern are defined by the level of risk estimated for each of the RME exposure scenarios in the *HHRA* and for each ecological receptor in the *ERA*. For the *HHRA*, COCs are

identified as those COPCs with risk estimates exceeding the risk threshold levels identified by EPA in the NCP: for carcinogenic chemicals, the risk threshold is an excess cancer risk estimate of one in one million (1×10^{-6}); for non-carcinogenic chemicals, the threshold is an HQ of 1. The COCs with risk estimates greater than these thresholds for human health are summarized in Table 7-6.

In the *ERA*, the risk threshold to identify a COC is an HQ of 1, which is the ratio of the exposure concentration or dose to the LOAEL. The ecological COCs with HQs greater than 1 are summarized in Table 7-7. Many COPCs for crab and fish were not selected as COCs due to the lack of toxicity values from which HQs could be calculated, which included selenium and most individual PAHs. Tributyltin was identified as a COC for benthic invertebrates based on porewater exposures and as a COC for crab. For fish, COCs are copper, TBT, and PCBs. For sandpiper, COCs in intertidal sediment are copper and lead.

7.4 DESIGNATION OF RISK DRIVERS

The final step in the characterization of risk in both the *HHRA* and *ERA* is to identify chemical contaminants that are the main drivers of risks. The purpose of identifying risk drivers is to provide focus for the development and evaluation of remedial alternatives in the FS. Risk drivers are identified based on the absolute magnitude of risk and on the relative contribution to total risk for a given human health exposure scenario or ecological receptor.

For the *HHRA*, the RME scenario with the highest excess cancer risks was tribal adult seafood consumption, whereas the tribal child seafood consumption scenario had the highest non-cancer risks. Of the 11 chemicals identified as COCs, four are risk drivers for both adult and child seafood consumption: PCBs, arsenic, cPAHs, and TBT (Table 7-6). Lead is an additional risk driver based on the child tribal seafood consumption scenario. As described previously, dioxins/furans are risk drivers based on their assumed likely presence at the Site, and the potential for associated cancer risks above regulatory thresholds.

For direct sediment exposures, the RME scenario with the highest excess cancer risks was the tribal clamming scenario at 120 days per year, for which risk drivers for intertidal sediment are arsenic, cPAHs, and dioxins/furans (Table 7-6). Risk drivers for intertidal sediment under the beach play scenario are the same as for the clamming scenario.

In the *ERA*, 11 COCs were identified in intertidal sediment and 25 COCs in subtidal sediment for the benthic invertebrate community. Of these COCs, three metals (arsenic, copper, and mercury) and total PCBs are risk drivers based on exceedances of the higher criteria in at least 6 percent of the stations (i.e., in more than 3 of the 51 stations) (Table 7-7).

For higher trophic ecological receptors such as fish, crab, and sandpiper, the number of COCs is limited, and similarly, the number of risk drivers is limited. Tributyltin is the sole risk driver for crab. For fish, all three COCs are risk drivers: copper, TBT, and total PCBs (Table 7-7). The risk drivers for the sandpiper are copper and lead in intertidal sediment (Table 7-7).

Table 7-8 contains a summary of the risk-driver COCs selected for combined subtidal plus intertidal sediment and for intertidal sediment only, for exposures of both human and ecological receptors.

Table 7-1.
Cancer Risks and Non-Cancer Hazard Estimates for RME Human Health Risk Assessment Scenarios (Page 1 of 2)

RME Scenario	Medium	COPC	Cancer Risk	Hazard Quotient	COC?
Adult Tribal Seafood Consumption – Tulalip Survey	Subtidal and Intertidal Sediment	Arsenic[1/]	**3×10^{-3}**	**5.8**	**YES**
		Cadmium	Not COPC	0.89	No
		Chromium	Not COPC	**1.1**[2/]	**YES**
		Copper	Not COPC	**1.2**	**YES**
		Mercury	Not COPC	0.40	No
		Zinc	Not COPC	**1.2**	**YES**
		Fluoranthene	Not COPC	0.06	No
		Pyrene	Not COPC	0.05	No
		TBT (as ion)	Not COPC	**89**	**YES**
		Pentachlorophenol	**3×10^{-6}**	0.001	**YES**
		cPAHs[3/]	**3×10^{-3}**	Not COPC	**YES**
		Total PCBs	**3×10^{-3}**	**72**	**YES**
		Total chlordane[4/]	**2×10^{-5}**	0.1	**YES**
		Total DDTs[4/]	**3×10^{-4}**	**1.5**	**YES**
		Dioxins/Furans	Not quantified		**YES**
		Total Excess Cancer Risk and Non-Cancer Hazard Index[5/]	9×10^{-3}	173	--
Child Tribal Seafood Consumption – Tulalip Survey	Subtidal and Intertidal Sediment	Arsenic[1/]	**5×10^{-4}**	**12**	**YES**
		Cadmium	Not COPC	**1.9**	**YES**
		Chromium	Not COPC	**2.4**[2/]	**YES**
		Copper	Not COPC	**2.6**	**YES**
		Mercury	Not COPC	**2.2**[2/]	**YES**
		Zinc	Not COPC	**2.6**	**YES**
		Fluoranthene	Not COPC	0.12	No
		Pyrene	Not COPC	0.11	No
		TBT (as ion)	Not COPC	**193**	**YES**
		Pentachlorophenol	6×10^{-7}	0.002	No
		cPAHs[3/]	**3×10^{-3}**	Not COPC	**YES**
		Total PCBs	**5×10^{-4}**	**154**	**YES**
		Total chlordane[4/]	**3×10^{-6}**	0.22	**YES**
		Total DDTs[4/]	**5×10^{-5}**	**3.2**	**YES**
		Dioxins/Furans	Not quantified		**YES**
		Total Excess Cancer Risk and Non-Cancer Hazard Index[5/]	4×10^{-3}	372	--
Netfishing	Subtidal and Intertidal Sediment	Antimony	Not COPC	0.02	No
		Arsenic[1/]	**3×10^{-5}**	0.1	**YES**
		Chromium	Not COPC	0.006	No
		cPAHs[3/]	**3×10^{-6}**	Not COPC	**YES**
		Total PCBs	4×10^{-7}	0.02	No
		Dioxins/Furans	Not quantified		**YES**

Table 7-1.
Cancer Risks and Non-Cancer Hazard Estimates for RME Human Health Risk Assessment Scenarios (Page 2 of 2)

RME Scenario	Medium	COPC	Cancer Risk	Hazard Quotient	COC?
		Total Excess Cancer Risk and Non-Cancer Hazard Index[5/]	3×10^{-5}	0.1	--
Beach Play	Intertidal Sediment	Antimony	Not COPC	0.5	No
		Arsenic[1/]	**7×10^{-5}**	**1.8**	**YES**
		Chromium	Not COPC	0.2	No
		Copper	Not COPC	0.1	No
		Vanadium	Not COPC	0.03	No
		cPAHs[3/]	**2×10^{-6}**	Not COPC	**YES**
		Dioxins/Furans	Not quantified		**YES**
		Total Excess Cancer Risk and Non-Cancer Hazard Index[5/]	7×10^{-5}	2.6	--
Clamming – 120 day/year	Intertidal Sediment	Antimony	Not COPC	0.08	No
		Arsenic[1/]	**1×10^{-4}**	0.35	**YES**
		Chromium	Not COPC	0.03	No
		Copper	Not COPC	0.01	No
		Vanadium	Not COPC	0.004	No
		cPAHs[3/]	1×10^{-6}	Not COPC	No
		Dioxins/Furans	Not quantified		**YES**
		Total Excess Cancer Risk and Non-Cancer Hazard Index[5/]	1×10^{-4}	0.5	--

Notes:
1/ Arsenic EPCs and risk estimates are based on inorganic arsenic.
2/ Based on alternative BSAFs developed from Lockheed West clam data and LDW site-wide data on fish and crabs, as used in an analysis of RME tribal seafood ingestion scenarios (see Section 6 of the HHRA).
3/ cPAHs are presented as benzo(a)pyrene equivalents.
4/ Tentatively identified chemical (JN-qualified).
5/ Total across all chemicals. This total is not directly interpretable for risk assessment, but a value greater than 1 suggests that an HQ may exceed 1 for individual endpoints.
Not COPC = not a contaminant of potential concern for that scenario, or the toxicity endpoint is not relevant, and hence cancer risk or hazard quotient not calculated.
COC = contaminant of concern, based on excess cancer risks > 1×10^{-6} or HQ > 1.
COPC = contaminant of potential concern
cPAH = carcinogenic polycyclic aromatic hydrocarbon
EPC = exposure point concentration
PCB = polychlorinated biphenyl
RME = reasonable maximum exposure
TBT = tributyltin

Table 7-2.
Intertidal Sediments Benthic Invertebrate Community Risk Potential

COPC	Detection Frequency (Percent) (n=9)	Percent of Stations > Low Criteria[1/]		Percent of Stations > High Criteria[2/]	
		No. of Stations	Percent	No. of Stations	Percent
Metals					
Antimony	100	0	0	0	0
Arsenic	100	5	56	5	56
Chromium	100	1	11	1	11
Cobalt	100	5	56	0	0
Copper	100	4	44	4	44
Lead	100	1	11	1	11
Mercury	100	1	11	0	0
Nickel	100	2	22	0	0
Selenium	100	0	0	0	0
Vanadium	100	2	22	0	0
Zinc	100	7	78	2	22
PAHs					
Acenaphthene	67	1	11	0	0
Benzo(a)anthracene	100	0	0	0	0
Benzo(a)pyrene	100	0	0	0	0
Benzo(b)fluoranthene	100	0	0	0	0
Benzo(g,h,i)perylene	100	0	0	0	0
Chrysene	100	0	0	0	0
Dibenzo(a,h)anthracene	78	0	0	0	0
Fluoranthene	100	0	0	0	0
Indeno(1,2,3-cd)pyrene	100	0	0	0	0
Phenanthrene	89	0	0	0	0
Total HPAH	100	0	0	0	0
PCBs					
PCBs (total)	100	0	0	0	0
Other SVOCs					
bis(2-ethylhexyl)phthalate	33	0	0	0	0
Pentachlorophenol	0	0	0	0	0

Notes:
1/ Low criteria = SQS, SL, NOAEL, or LAET.
2/ High criteria = CSL, ML, LOAEL, or 2LAET.
COPC = contaminant of potential concern
CSL = cleanup screening level (SMS)
HPAH = high-molecular-weight polycyclic aromatic hydrocarbon
LAET = lowest apparent effects threshold
2LAET = second lowest apparent effects threshold
LOAEL = lowest observed adverse effect level
ML = maximum level (DMMP)
NOAEL = no observed apparent effects level
OC = organic carbon
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SL = screening level (DMMP)
SQS = sediment quality standards (SMS)
SVOC = semivolatile organic compound

Table 7-3.
Subtidal Sediments Benthic Invertebrate Community Risk Potential

COPC	Detection Frequency (Percent) (n=42)	Percent of Stations > Low Criteria[1/]		Percent of Stations > High Criteria[2/]	
		No. of Stations	Percent	No. of Stations	Percent
Metals					
Antimony	100	1	2.4	0	0
Arsenic	100	6	14	4	9.5
Chromium	100	1	2.4	1	2.4
Cobalt	100	6	14	0	0
Copper	100	8	19	8	19
Lead	100	1	2.4	0	0
Mercury	100	21	50	17	41
Nickel	100	0	0	0	0
Selenium	38	8	19	0	0
Vanadium	100	10	24	0	0
Zinc	100	6	14	1	2.4
PAHs					
Acenaphthene	100	2	4.8	0	0
Benzo(a)anthracene	100	3	7.1	0	0
Benzo(a)pyrene	100	4	9.5	0	0
Benzo(b)fluoranthene	100	7	17	2	4.8
Benzo(g,h,i)perylene	100	9	21	0	0
Chrysene	100	8	19	0	0
Dibenzo(a,h)anthracene	100	6	14	0	0
Fluoranthene	100	10	24	0	0
Indeno(1,2,3-cd)pyrene	100	10	24	0	0
Phenanthrene	100	6	14	0	0
Total HPAH	100	9	21	0	0
PCBs					
PCBs (total)	100	27	64	7	17
Other SVOCs					
bis(2-ethylhexyl)phthalate	95	3	7.1	0	0
Pentachlorophenol	48	3	7.1	0	0

Notes:
1/ Low criteria = SQS, SL, NOAEL, or LAET.
2/ High criteria = CSL, ML, LOAEL, or 2LAET.
COC = contaminant of concern
COPC = contaminant of potential concern
CSL = cleanup screening level (SMS)
HPAH = high-molecular-weight polycyclic aromatic hydrocarbon
LAET = lowest apparent effects threshold
2LAET = second lowest apparent effects threshold
LOAEL = lowest observed apparent effects level
NOAEL = no observed apparent effects level
ML = maximum level (DMMP)
OC = organic carbon
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SL = screening level
SQS = sediment quality standards (SMS)
SVOC = semivolatile organic compound

Table 7-4.
Summary of Risks for Crabs and Fish

COPC	Crab		Fish – Tissue Residue		Fish – Dietary		COC?
	HQ NOAEL	HQ LOAEL	HQ NOAEL	HQ LOAEL	HQ NOAEL	HQ LOAEL	
Metals							
Chromium	0.1	0.02	--	--	0.1 – 0.3	--	No
Copper	0.3	--	--	--	**28 – 36**	**14 – 18**	YES
Lead	--	--	--	--	0.02 – 0.07	--	No
Mercury	0.01	0.01	0.3	0.2	--	--	No
Selenium	--	--	--	--	--	--	--
PAHs							
Acenaphthene	--	--	--	--	--	--	--
Acenaphthylene	--	--	--	--	--	--	--
Anthracene	--	--	--	--	--	--	--
Benzo(a)anthracene	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	0.009 – 0.01	0.007 – 0.009	No
Benzo(b)fluoranthene	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--
Benzo(k)fluoranthene	--	--	--	--	--	--	--
Benzofluoranthenes (total)	--	--	--	--	--	--	--
Chrysene	--	--	--	--	--	--	--
Dibenzo(a,h)anthracene	--	--	--	--	--	--	--
Fluoranthene	--	--	--	--	--	--	--
Fluorene	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	--	--	--	--
Phenanthrene	--	--	--	--	--	--	--
Pyrene	--	--	--	--	--	--	--
Total PAHs	--	--	--	--	0.09 – 0.5	0.03 – 0.2	No
Organometals							
Tri-n-butyltin	**202**	--	**158**	**18**	--	--	YES
Other SVOCs							
Pentachlorophenol	--	--	0.005	0.003	--	--	No
PCBs							
Aroclor 1254	--	--	--	--	--	--	--
Aroclor 1260	--	--	--	--	--	--	--
Aroclor 1268	--	--	--	--	--	--	--
Total PCBs	**9**	**0.9**	**6 – 31**	**1 – 6**	--	--	YES
Organochlorine Pesticides							
Total DDT	**10**	**7**	**1**	**1**	--	--	YES
Methoxychlor	**3**	0.33	**2**	0.4	--	--	No
Mirex	--	--	0.01	0.002	--	--	No
Chlordane (total, gamma)	0.05	0.02	0.2	0.11	--	--	No

Notes:
Bold identifies HQs greater than 1.
-- = Not a COPC for that receptor or pathway, or lack of toxicity data or modeling parameter for tissue concentration.
COC = contaminant of concern
COPC = contaminant of potential concern
DDT = dichlorodiphenyltrichloroethane
HQ = hazard quotient
LOAEL = lowest-observed-adverse-effect level
NOAEL = no-observed-adverse-effect level
PAHs = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SVOC = semivolatile organic compound

Table 7-5.
Summary of Risks for Spotted Sandpiper

COPC	NOAEL HQ	LOAEL HQ	COC?
Chromium	**6**	1	No
Copper	**4**	**3**	YES
Lead	**48**	**14**	YES
Vanadium	**1**	0.6	No
Total PCBs	0.1	0.05	No

Notes:
Bold identifies HQs greater than 1.
COC = contaminant of concern
COPC = contaminant of potential concern
HQ = hazard quotient
LOAEL = lowest observed adverse effect level
NOAEL = no observed adverse effect level
PCB = polychlorinated biphenyl

Table 7-6.
Summary of Contaminants of Concern and Risk Drivers for Human Health

Scenario:	**Human Health – Seafood Ingestion**	**Human Health – Direct Exposure**	**Human Health – Direct Exposure**
Medium:	**Subtidal and Intertidal Sediment**	**Subtidal and Intertidal Sediment**	**Intertidal Sediment**
Contaminants of Potential Concern (COPCs)	Tribal Adult and Child – 16 COPCs Metals: arsenic, cadmium, chromium, copper, lead, mercury, zinc, tributyltin Organics: cPAHs, fluoranthene, pyrene, pentachlorophenol, total PCBs, total chlordane, total DDT	Netfishing – 6 COPCs Metals: antimony, arsenic, chromium, lead Organics: cPAHs, total PCBs	Beach play – 7 COPCs Metals: antimony, arsenic, chromium, copper, lead, vanadium Organics: cPAHs Clamming, tribal – 7 COPCs Metals: antimony, arsenic, chromium, copper, lead, vanadium Organics: cPAHs
Contaminants of Concern (COCs)	Tribal Adult – 9 COCs Metals: arsenic, chromium, copper, lead, zinc, tributyltin Organics: cPAHs, total PCBs, dioxins/furans[1/] Tribal Child – 11 COCs Metals: arsenic, cadmium, chromium, copper, lead, mercury, zinc, tributyltin Organics: cPAHs, total PCBs, dioxins/furans[1/]	Netfishing – 3 COCs Metals: arsenic Organics: cPAHs, dioxins/furans[1/]	Beach play – 3 COCs Metals: arsenic Organics: cPAHs, dioxins/furans[1/] Clamming, tribal – 2 COCs Metals: Arsenic Organics: dioxins/furans[1]
Risk Drivers	Tribal Adult – 5 Risk drivers Metals: arsenic, tributyltin Organics: cPAHs, total PCBs, dioxins/furans[1/] Tribal Child – 6 Risk drivers Metals: arsenic, lead, tributyltin Organics: cPAHs, total PCBs, dioxins/furans[1/]	Netfishing – 3 risk drivers Metals: arsenic Organics: cPAHs, dioxins/furans[1/]	Beach play – 3 Risk drivers Metals: arsenic Organics: cPAHs, dioxins/furans[1/] Clamming, tribal – 2 risk driver Metals: arsenic Organics: dioxins/furans [1/]

Notes:
1/ Dioxins/furans were identified as COCs and risk drivers for seafood consumption and direct contact scenarios based on the assumption that they would be present in tissue and sediments at concentrations above regulatory risk thresholds.
cPAH = carcinogenic polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl

Table 7-7.
Summary of Contaminants of Concern and Risk Drivers for Ecological Receptors

Ecological Receptor:	Benthic Invertebrate Community	Crabs	Fish	Sandpiper
Medium:	**Subtidal and Intertidal Sediment**	**Subtidal and Intertidal Sediment**	**Subtidal and Intertidal Sediment**	**Intertidal Sediment**
Contaminants of Potential Concern (COPCs)	Benthic invertebrates – 27 COPCs 11 Metals, TBT PAHs (10 + total HPAH), total PCBs, 1 phthalate, pentachlorophenol total chlordanes [2/]	Crabs – 34 COPCs 5 Metals, TBT 16 PAHs pentachlorophenol total PCBs + Aroclors 7 Organochlorine pesticides[2/]	Fish – 34 COPCs 5 Metals, TBT 16 PAHs pentachlorophenol total PCBs + Aroclors 7 Organochlorine pesticides[2]	Sandpiper – 8 COPCs 4 Metals, TBT 2 PAHs 1 PCB Aroclor
Contaminants of Concern (COCs)	Benthic invertebrates – intertidal 11 COCs above lesser criteria[1/] in at least one station 9 Metals, TBT (porewater), 1 PAH Benthic invertebrates – subtidal 25 COCs above lesser criteria[1/] 10 Metals, TBT (porewater) 10 PAHs, HPAH, Total PCBs 2 SVOCs	Crabs – 2 COCs TBT total DDTs[2/] (most COPCs not selected as COCs due to lack of crab toxicity data)	Fish –3 COCs copper TBT total PCBs (many COPCs not selected as COCs due to lack of fish toxicity data)	Sandpiper – 2 COCs, LOAEL HQ >1 copper lead
Risk Drivers	Benthic invertebrates – combined subtidal + intertidal 4 COCs above greater criteria[1/] in at least 6 percent of stations 3 Metals (arsenic, copper, mercury) Total PCBs	Crabs – 1 Risk driver TBT	Fish – 3 risk drivers copper TBT total PCBs	Sandpiper – 2 risk drivers, LOAEL HQ >1 copper lead

Notes:
1/ Lesser criteria = SQS (sediment quality standard), DMMP SL, NOAEL, or LAET; greater criteria = CSL (cleanup screening level), DMMP ML, LOAEL, or 2LAET; risk drivers are identified as COCs exceeding the greater criteria in at least 6 percent of stations (i.e., in more than 3 of the 51 stations).
2/ Qualified as estimated and tentatively identified, identification not confirmed; not selected as a risk driver.

2LAET = second lowest apparent effects threshold
cPAH = carcinogenic polycyclic aromatic hydrocarbon
DDT = dichlorodiphenyltrichloroethane
DMMP = Dredge Material Management Program
HQ = hazard quotient
LAET = lowest apparent effects threshold
LOAEL = lowest observed adverse effects level
ML = maximum level
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SL = screening level
SVOC = semivolatile organic compound
TBT = tributyltin

Table 7-8.
Summary of Risk-Driver Contaminants of Concern at the Lockheed West Site

Sediment	Contaminant of Concern	Human Exposure Scenario	Ecological Receptor
Subtidal plus Intertidal Sediment	Arsenic	Tribal adult and child seafood ingestion, netfishing	Benthic invertebrates
	Copper	--	Benthic invertebrates, fish
	Lead	Tribal child seafood ingestion	--
	Mercury	--	Benthic invertebrates
	Tributyltin (TBT)	Tribal adult and child seafood ingestion	Crabs, fish
	Carcinogenic polycyclic aromatic hydrocarbons (cPAHs)	Tribal adult and child seafood ingestion, netfishing	--
	Total polychlorinated biphenyls (PCBs)	Tribal adult and child seafood ingestion	Benthic invertebrates, fish
	Dioxins/Furans	Tribal adult and child seafood ingestion, netfishing	--
Intertidal Sediment	Arsenic	Beach play, clamming	--
	Copper	--	Sandpiper
	Lead	--	Sandpiper
	cPAHs	Beach play	--
	Dioxins/Furans	Beach play, clamming	--

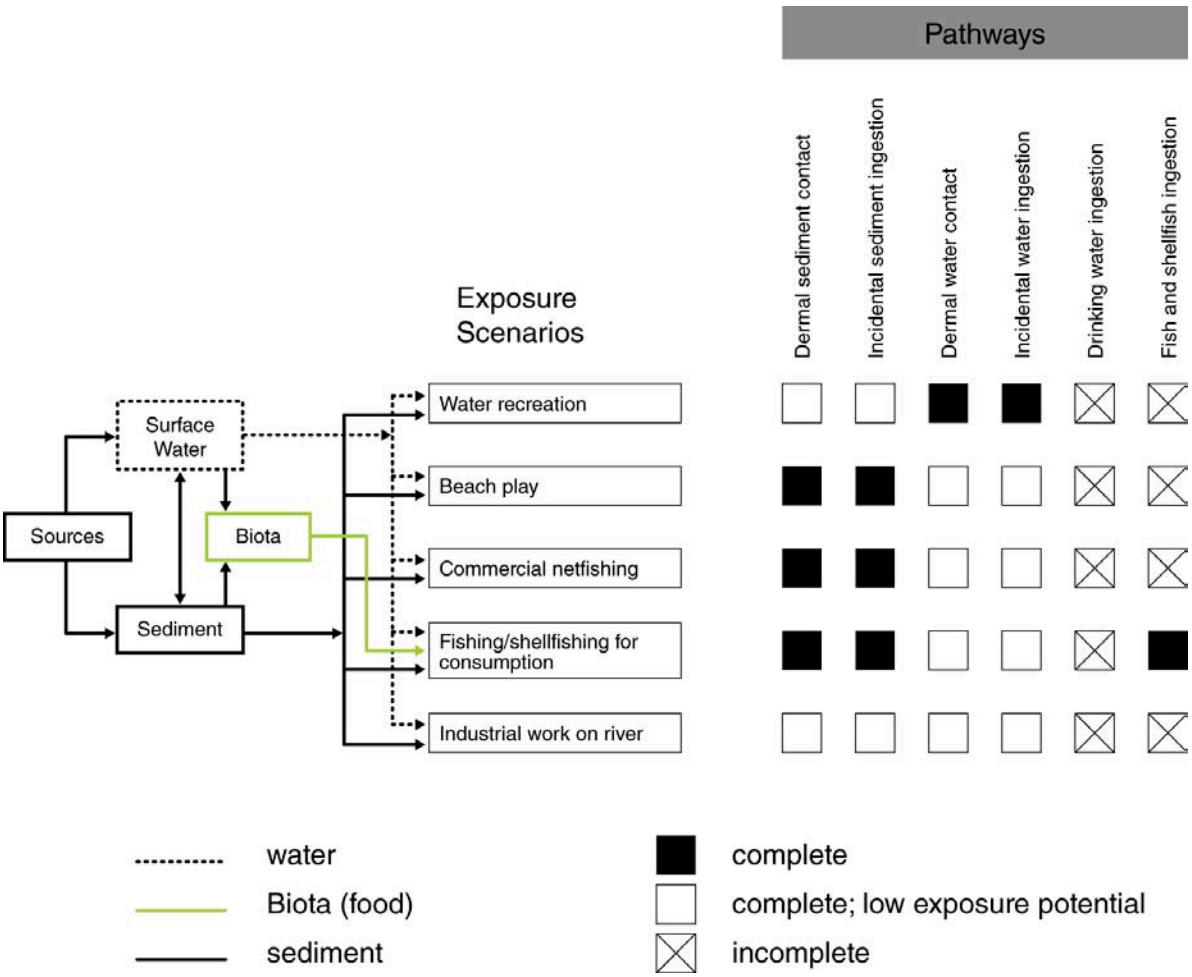
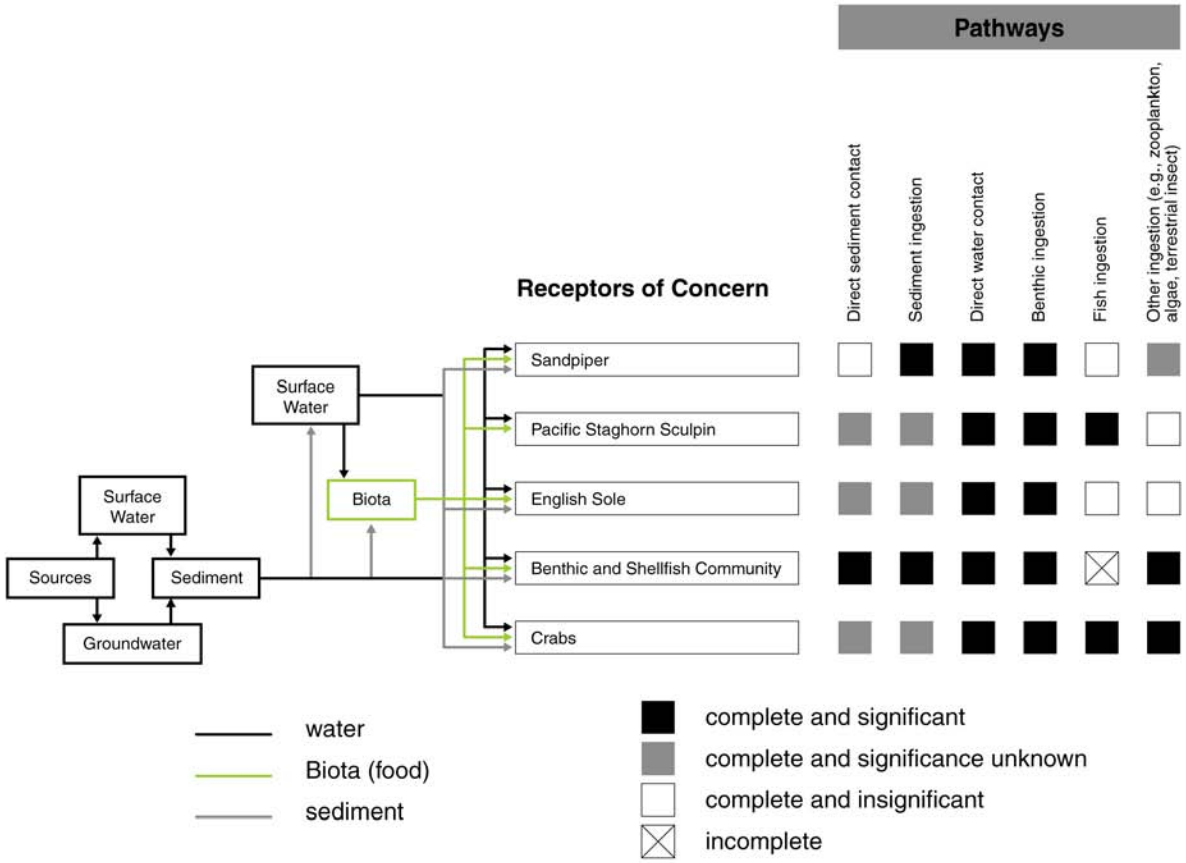


Figure 7-1. Conceptual Site Model for Human Health Risk Assessment at the Lockheed West Site



Note: Groundwater at the adjacent PSR site may impact sediment benthos through transition zone water.

Figure 7-2. Conceptual Site Model for Benthic Invertebrates, Fish, and Wildlife at the Lockheed West Site

SECTION 8
Key Findings of the Remedial Investigation

This section summarizes and highlights major and key findings of the RI. The summarized findings represent important considerations for development of remedial action objectives and alternatives within the feasibility study. Major findings about the conceptual site model, physical characterization and nature and extent of contamination, source control evaluation, chemical fate and transport, and risk assessments are summarized in the following sections.

8.1 CONCEPTUAL SITE MODEL

In the *RI/FS Work Plan*, a preliminary conceptual site model was developed for the general mechanisms that potentially could have resulted in the sediment contamination at the Site. The data collected during the RI generally support the preliminary conceptual site model.

The significant sources of sediment contamination are the historic shipyard operations and activities and transport from off-site sources and other regional activities. Transport and discharge from uplands groundwater and atmospheric deposition do not appear to have contributed significantly to the sediment contamination.

Ongoing contribution of contaminants to Site sediments are primarily from the deposition of contaminants by in-water sediment and water-transport processes. Upland, outfall, and atmospheric contributions are likely to be low.

The conceptual site model is summarized as follows:

- Contaminants at the Lockheed West Site that are related to shipyard activities include, but are not limited to, PAHs, PCBs, arsenic, copper, lead, mercury, TBT, and zinc.

- Primary historical pathways for these contaminants include historical ship operations and activities associated with the dry docks, shipway and pier-side ship construction and maintenance, along with direct discharge of materials from overwater structures.
- Potential migration pathways for Site-related contaminants to the sediments include the SW Florida Street Outfall and surface erosion of impacted soils. However, because of source controls recently implemented, the potential for future (post-remediation) recontamination from these sources is low.
- Groundwater transport of upland contaminants to the sediments is possible, though it does not appear to be a significant ongoing contamination source based on the source control evaluation, the previous studies of the former shipyard uplands and neighboring PSR site, and upland remediation activities.
- Sediments in the Lockheed West Site area appear to be relatively stable and characterized by a low depositional rate based on the hydrographic survey performed.
- There is some evidence that regional influences have affected and continue to affect the Site, especially on the eastern side of the Site where the effect of the Lower Duwamish Waterway and the West Waterway is most prevalent. Surface sediment concentrations of mercury and PCBs were relatively greater on this part of the Site, and sediment studies of adjacent areas in the West Waterway indicate that these chemicals are widespread throughout the area.
- Deposition of sediment from the West Waterway farther upstream in the Lower Duwamish Waterway, and from Elliott Bay has a high likelihood of future recontamination of the Site above lower potential cleanup goals (Tetra Tech, 2009b); however, the potential for recontamination above the SMS levels is low. These conclusions are based partly on cap monitoring results from nearby sediment cleanup sites within West Waterway, which suggest that relative to the low potential cleanup levels, such as the concentrations from the "Bold Study," there is an ongoing transport and deposition of sediment contamination in the general area that potentially will result in recontamination of the Lockheed West Site remedy.

8.2 NATURE AND EXTENT

Data were collected at the Site to address data gaps as identified in the *RI/FS Work Plan*. Major findings for the physical characteristics of the Site and the nature and extent of contamination are discussed in this section.

A bathymetric survey and shoreline surveys were conducted to provide a physical characterization of the Site and adjacent areas and to evaluate Site sediment stability. The evaluation of the bathymetric survey indicates that, based on the presence of distinct historic features in the Site area, there is a low net depositional sedimentation rate and sediments are relatively stable. This conclusion was also supported by wave analysis.

The shoreline surveys show that current conditions are typical of a highly modified and industrial shoreline. The surveys documented the presence of several pipes and the SW Florida Street Outfall along the eastern and northern shorelines. The surveys also documented that the substrate along the shore included medium-grained sand, shell hash, small- to medium-size cobbles, medium to large riprap, concrete keel blocks, cut-off and broken-off wood pilings, and debris, including trash, wire rope, concrete and ductile iron piping, and portions of deteriorated wooden bulkheads. Bulkheads along the shore include single wooden, double wooden, steel sheetpile, and concrete bulkheads with the wooden bulkheads observed to be in poor to very poor condition and the concrete and steel sheetpile bulkheads were observed to be in good condition. The shoreline surveys documented the presence of a single small intertidal beach area located along the West Waterway between the Terminal 5 pier and the SW Florida Street Outfall with very limited undisturbed intertidal habitat. Intertidal and subtidal sediments consisted primarily of sand and silt.

Samples of surface and subsurface sediment were collected during the RI field sampling events to define the nature and extent of contamination at the Lockheed West Site. The results of the sampling and analysis conducted showed that metals including arsenic, cadmium, copper, lead, mercury, and zinc along with organics including PCBs, LPAHs, HPAHs, pentachlorophenol, and bis(2-ethylhexyl)phthalate were detected above the SQS in the surface and subsurface sediments. Areas with sediment concentrations above the SQS included the former dry docks and along the former piers. In addition, the intertidal area of the former shipway had concentrations above the SQS for metals including arsenic, copper, lead, and zinc.

For the purpose of establishing a remedy boundary to evaluate as part of the FS, the horizontal extent of potential Site-related sediment contamination in the Lockheed West Site (Figure 4-44) can be defined by the following:

- The top of the slope, also where the Outer Harbor Line is shown to the north and extending east along the top of bank contour to the West Waterway OU boundary;
- The PSR Marine Sediment Unit boundary to the west;
- The West Waterway OU to the east; and
- The southern boundary, which is defined by both the uplands area of Terminal 5 and the in-water area between the Terminal 5 uplands and the West Waterway OU, where sediment concentrations are above the SQS.

The data for the sediment cores presented in Figures 4-26 through 4-32 show that the vertical extent of the Site-related sediment contamination in the study area can be generally defined using SQS levels. At a limited number of locations, the depth of contamination above the SQS is not completely defined. The vertical extent of contamination based on a comparison to the SQS shows that in some areas of the dry docks, the depth of contamination extends to 12 feet. In areas outside of the dry docks, the depth of contamination where concentrations were detected above the SQS ranges between 0.5 foot and 6.9 feet. The data cannot define the vertical extent of sediment contamination for the risk-driver contaminants when compared to lower screening values (e.g., RBTCs and "Bold Study" background levels; refer to Section 9.0 for further discussion).

During the design phase, additional sampling may be conducted to further delineate the extent of contamination in some areas of the Site.

8.3 SOURCE CONTROL

The evaluation of contaminant sources to the Site sediments was completed as part of the RI and concluded that off-site, in-water sources are potential sources of contaminants and Site sediments are expected to reach a long-term equilibration at levels that are above the RBTCs or natural background levels. Potential sources of remedy recontamination are outside of the direct control of Lockheed Martin and include overwater uses and spills, wastewater discharges, CSOs,

stormwater discharges, upland contaminated groundwater discharges, and contaminated in-water sediment transport and deposition.

Discussion in the *Source C ontrol Information and D ata G ap R eport* and *Source C ontrol Evaluation R eport* indicated that in-water contaminated sediment transport and deposition represents a relatively high likelihood of remedy recontamination for some risk drivers (e.g., PCBs, cPAHs, arsenic) at concentrations above the RBTCs and natural background concentrations. Other potential sources such as contaminated groundwater, stormwater, overwater uses and spills, CSO discharges, wastewater discharges, and atmospheric deposition were determined to represent a relatively low likelihood of remedy recontamination based on a review of available information.

8.4 FATE AND TRANSPORT

An evaluation of the chemical properties for the contaminants detected at concentrations above the SQS levels in the sediments at the Site was performed to determine the most important fate and transport processes. The contaminants detected at the Site are generally hydrophobic in nature and likely to be bound to sediment particles. The potential for contaminants to be transported in the dissolved phase is low. Transport of contaminants will be primarily driven by movement of sediments at the Site. The Site is characterized by a low rate of net deposition and stable sediments as determined by the evaluation of the bathymetry data and an analysis of wave-generated bottom shear stress. However, the potential does exist for post-remedy recontamination by upgradient sources through sediment transport and deposition, as evidenced by the higher levels of PCBs and mercury present in surface sediments in some portions of the Site.

8.5 HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT RESULTS

The objective of the risk assessments was to identify contaminants, human and ecological receptors, and the pathways for exposure that result in unacceptable risks to human health and the environment. The risk assessments identified COCs and the contaminants that are predicted have the highest contribution to estimated human health and environmental risks.

The COCs were identified as those contaminants that, based on the human health assessment, have an excess cancer risk estimate of one in 1 million (1×10^{-6}) for carcinogenic chemicals and an HQ greater than 1 for non-carcinogenic chemicals. The COCs were also identified as those contaminants with an HQ greater than 1 from a comparison of the exposure concentration or dose to the tissue residue value based on the LOAELs in the ecological risk assessment. In addition, dioxins and furans were identified as COCs based on their assumed presence in the sediments and seafood and assumed cancer-risk estimates above regulatory thresholds.

Risk-driver COCs were identified based on the absolute magnitude or risk and the relative contribution to total risk for a given human health exposure scenario or ecological receptor. Eight COCs were identified as risk drivers for the following areas of the Site. For subtidal and intertidal sediments, the following risk-driver COCs were summarized in Table 7-8 and are listed here:

- Arsenic – tribal adult and child seafood ingestion, netfishing, beach play, clamming, benthic invertebrates;
- Copper – benthic invertebrates, fish, sandpiper;
- Lead – tribal child seafood ingestion; sandpiper;
- Mercury – benthic invertebrates;
- TBT – tribal adult and child seafood ingestion; crabs, fish;
- cPAHs – tribal adult and child seafood ingestion, netfishing, beach play;
- Total PCBs – tribal adult and child seafood ingestion; benthic invertebrates, fish; and
- Dioxins/furans – tribal adult and child seafood ingestion, netfishing, beach play, clamming.

8.6 SUMMARY OF KEY FEASIBILITY STUDY CONSIDERATIONS

The data collected in the RI provide the basis for the evaluation of the remedial alternatives for the Site. The following are the key considerations from the results of the RI to be used in the FS:

- The Lockheed West Site represents a net depositional area characterized by a low depositional rate and relatively stable sediments.

- The primary Site contaminants based on the RI data collected are primarily the shipyard-related chemicals including the following: arsenic, copper, lead, mercury, PCBs, cPAHs, and TBT. The risk drivers for human-health and ecological risks from sediment contamination are arsenic, copper, lead, mercury, PCBs, cPAHs, TBT, and dioxins/furans.
- The vertical extent of the sediment contamination has been generally defined based on SQS levels for the purposes of evaluating remedial alternatives in the FS as is described in Section 4.0.
- The horizontal extent of sediment contamination has been defined for the purposes of evaluating remedial alternatives in the FS and is shown in Figure 4-44. The process for defining the extent of contamination based on comparisons with multiple screening levels and background data sets is presented in detail in Section 4.0. It is anticipated that further definition of the nature and extent will be performed as part of the design studies to ensure efficient implementation of the selected remedy.
- The evaluation of contaminant sources to the Site sediments was completed as part of the RI and concluded that off-site, in-water sources are potential sources of contaminants and Site sediments are expected to reach a long-term equilibration at levels that are above the RBTCs or natural background levels.

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SECTION 9

Remedial Action Objectives and Preliminary Remediation Goals

9.1 INTRODUCTION

This section identifies a set of narrative (i.e., non-numerical) RAOs for the Site, which provide the foundation upon which preliminary numerical remediation goals, cleanup levels, and remediation alternatives can be developed. The RAOs have been developed to guide the evaluation of remediation alternatives so that they are protective of human health and ecological receptors at the Site. The step of identifying narrative RAOs translates the findings of the RI and human health and ecological risk assessments into a series of objectives to be addressed in the development of remedial alternatives in the FS. The RAOs pertain to the specific exposure pathways and receptors evaluated in the risk assessment and for which potentially unacceptable risks were identified.

The PRGs are the contaminant endpoint concentrations or risk levels associated with each RAO that are believed to be sufficient to protect human health and the environment based on available Site information (EPA, 1997b). A range of potential PRGs to achieve the RAOs is evaluated in this section resulting in identification of specific PRGs for each RAO. The PRGs are intended to comply with chemical-specific ARARs (EPA, 1991a). For the Lockheed West Site, PRGs are numerical concentrations or ranges of concentrations in sediment that protect a particular receptor from unacceptable exposure to a contaminant by a specific pathway. The PRGs are expressed as sediment concentrations for the identified risk drivers.

The RAOs and numerical goals to achieve them form the basis for the development of remedial alternatives in the FS. The FS lays the groundwork for development of cleanup alternatives that represent the best balance for managing risks to both human health and the environment. The estimates of human health and ecological risks, together with federal, state, and local regulatory requirements (i.e., ARARs), are considered during definition of RAOs and development of

PRGs. The development of RAOs and numerical PRGs in this section provides the foundation for cleanup levels and remediation alternatives. The final cleanup levels and alternatives will be established by EPA in the ROD for the Site.

9.1.1 Objective of the RAO Section

The RAOs are needed to support remedial action planning for the Site and to clearly articulate the intent of any remedial actions that may be undertaken to address risks to human health and/or ecological receptors at the Site. Preliminary remediation goals are then developed as numerical values to address the RAOs. The PRGs are the target concentrations in the affected media that correspond to the specific RAOs. Numeric PRG values also require information on how they will be spatially applied (e.g., point-by-point, sitewide) for each RAO. For example, if the RAO is protection of humans from incidental ingestion of sediment during a recreational activity, the PRG may be the sitewide average concentration of a contaminant of concern in the sediment that corresponds to an acceptable risk level for that activity. Establishment of RAOs and associated PRGs enables evaluation of various remedial alternatives that are identified for the Site relative to their ability to reduce risks to human health and ecological receptors to acceptable levels.

In the development of PRGs for the Site, this section includes ARARs, approaches for developing background values for the Site, and risk-based concentrations in sediment that were developed in the *HHRA* and *ERA*. The numerical PRGs have been developed to consider risk-based concentrations and background values for each COC identified in the human health and ecological risk assessments and to comply with chemical-specific ARARs. The *RAO Memorandum* included multiple approaches to determining chemical concentrations for background and a summary of preliminary results of those approaches. The EPA will consider PRGs in developing final cleanup levels in the ROD for the Site.

In summary, the objectives of the analysis incorporated in this section are to identify and define the following:

- ARARs and other standards or criteria to be considered;
- Narrative RAOs that address the primary exposure pathways, receptors, and risk drivers identified in the risk assessments;
- Development of sediment RBTCs;

- The approach to developing and using background concentrations;
- Analytical reporting limits/practical quantitation limits (PQLs) for COCs; and
- The approach to developing PRGs for the RAOs, based on the identified COCs, RBTCs, background concentrations, and analytical quantitation/reporting limits.

9.1.2 Regulatory Guidance

The identification of federal, state, and local regulatory requirements is a key component in the development of preliminary RAOs and the planning, evaluation, and selection of comprehensive remedial action alternatives. These requirements are necessary to evaluate the appropriate extent of Site cleanup, scope and formulate remedial alternatives, and control the implementation of the selected remedial action. Regulatory requirements are further discussed in Section 9.2.

Guidance documents and other sources for guidance on developing RAOs for the Lockheed West Site consist of the following documents:

- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988)
- *Risk Assessment Guidance for Superfund. Volume 1. Human Health Evaluation Manual. Part B, Development of Preliminary Remediation Goals* (EPA, 1991a)
- *A Guide for Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents* (EPA, 1999c).
- The draft LDW RAO Memorandum (RETEC and Windward, 2007) and the draft LDW FS (AECOM, 2009), as modified by EPA and Ecology comments (EPA and Ecology, 2009).

9.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

In addition to ensuring that human and ecological receptors are protected, remedial actions to clean up a site must take into account ARARs, which are derived from promulgated federal, state, and tribal standards and requirements. The identification of ARARs for the Lockheed West Site is an iterative process. The list of ARARs changes during the various phases of the remedial process and has been updated, as appropriate, since the preliminary ARAR list presented in the *RI/FS Work Plan*. The ARARs could change due to changes in remedial actions during the FS. Final ARAR determinations will be made by EPA during the preparation of the ROD.

The preliminary identification of ARARs for the Lockheed West Site was presented in the *RI/FS Work Plan* and they are updated here based on potential remedial actions identified as part of the FS development. This subsection identifies ARARs for cleanup of the Lockheed West Site. Section 12.0 of this document evaluates whether the remedial alternatives developed for cleanup of the Lockheed West Site comply with these ARARs.

According to the NCP (40 CFR 300.5), applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. A requirement may not be applicable, but nevertheless could be relevant and appropriate. Relevant and appropriate requirements address problems or situations sufficiently similar to those encountered at CERCLA sites that their use is well-suited to the particular site.

Washington State has promulgated environmental regulations to implement certain of these major federal programs; in cases where the state requirement is more stringent than the federal requirement, the state requirement is the ARAR.

In addition, some federal, state, and local environmental and public health agencies may develop criteria, advisories, guidance documents, and proposed standards that are not legally enforceable but that contain useful information for implementing a cleanup remedy or selecting cleanup levels. These fall into the category of criteria “to be considered” (referred to as TBCs); TBCs are not mandatory, but may complement the identified ARARs.

The ARARs may be categorized as 1) chemical-specific, 2) action-specific, and 3) location-specific. Some ARARs fit neatly into a single category, while others may fall into more than one category. To address this overlap, Table 9-1 identifies ARARs by general topic and includes a reference to whether the ARAR is chemical-, action-, or location-specific. Table 9-2 identifies other legal, permitting, or administrative requirements for the Lockheed West Site.

9.3 PRELIMINARY REMEDIAL ACTION OBJECTIVES

Remedial action objectives provide a general description of what the cleanup will accomplish and serve as the design basis for the remedial alternatives developed in the FS (EPA, 1999c). The

EPA (1988) guidance specifies that RAOs are to be developed based on the results of the human health and ecological risk assessments because RAOs are medium-specific or operable unit-specific goals designed to protect human health and the environment. The RAOs should be as detailed as possible without limiting the range of possible alternatives. The EPA (1999c) guidance states that RAOs should specify the following:

- Exposure pathways and receptors and the COCs, and
- Acceptable chemical concentration or range of concentrations for each exposure pathway.

Section 7.0 of this report discusses the populations, receptors, exposure pathways, and COCs identified in the *HHRA* and *ERA*. Narrative RAOs are presented here that describe the goals that address the risks determined from the findings of the risk assessments. Numeric values for the COCs and/or risk drivers that are associated with the RAOs are presented in Section 9.4.

The conceptual site model developed in the *Source Control Evaluation Report* and summarized in Section 2.3 (refer to Figure 2-10) identifies sediment as the medium of concern, which is also identified in the conceptual site models discussed in Section 7.0 for the risk assessments for the Lockheed West Site, and thus is the medium of focus of the RAOs. General improvements in the quality of surface water at the Site and compliance with Washington water quality standards are expected, as are decreases in site-related contaminant levels in tissues of marine organisms at the Site, following sediment cleanup and implementation of additional source control measures. Therefore, surface water and marine organism tissue at the Site are addressed by the descriptive text of the RAOs presented in this document.

9.3.1 Narrative Remedial Action Objectives

The following is a list of narrative RAOs that have been identified for the Lockheed West Site based on the results of the risk assessments. These RAOs will be subject to modification until the time the ROD is signed. In particular, RAOs may be modified in the ROD to be more specific about endpoints to achieve the objectives, and the ROD may set forth more specific objectives based on risk, background, ARARs, or some combination of these.

As discussed in the *RI/FS Work Plan* and reiterated in the risk assessments, Lockheed Martin plans to actively remediate the entire Lockheed West Site sediment to achieve a final remedy.

Because of active remediation, all of the RAOs to reduce risks due to direct and indirect sediment exposures would be achieved through the planned remediation. Four RAOs for the Lockheed West Site were developed and approved by EPA in the June 2010 *RAO Memorandum* including the following:

> *RAO 1. Reduce human health risks associated with the consumption of resident Lockheed West sea food b y red ucing sed iment and s urface w ater concentrations of C OCs t o protective levels*.
>
> > *Note: Expected improvements to surface water quality will be achieved through remediation of site sediments; no active remediation of surface water will be conducted.*
>
> The *HHRA* evaluated exposure scenarios that were identified in the *RI/FS Work Plan* as likely presenting the highest risks for the Site, based on preliminary risk analysis and comparisons with the nearby LDW HHRA. Per EPA guidance (EPA 1989, Section 6.1.2), RME scenarios should be used to formulate RAOs and evaluate cleanup alternatives at Superfund sites. The RME scenario with the highest risk estimates for the Lockheed West Site was the tribal consumption of fish and shellfish exposed to Site sediments. The carcinogenic risk-driver COCs identified for this scenario are PCBs, cPAHs, and arsenic in resident seafood organisms. Although cancer risks associated with consumption of dioxins/furans in resident seafood were not quantitatively assessed in the *HHRA*, human health risks for dioxins/furans in seafood are assumed to be above risk regulatory thresholds. Consequently, dioxins/furans are also considered a risk-driver COC for the tribal consumption of seafood. It is expected that sediment concentrations of dioxins and furans resulting in acceptable health risks for seafood consumption would likely be below background concentrations, similar to assumptions EPA has made about the upstream LDW.
>
> Meeting this RAO will require that sitewide average COC concentrations in surface sediments be reduced to achieve a corresponding reduction in the concentration of COCs in fish and shellfish tissues. Exposure of these organisms to contaminants in sediment occurs within the biologically active zone, which includes the surficial sediment layer where organisms might have direct contact exposure, and the upper layers of sediment

where prey organisms may take up sediment contaminants. Reducing concentrations of COCs in the upper surface layers of sediment will help reduce concentrations of COCs in fish and shellfish tissue that may occur through direct contact with sediment, and will reduce the transfer of COCs to sediment porewater and to surface water, which may also be a source of sediment contaminants to fish and shellfish tissue. Reducing concentrations of COCs in sediment that may transfer to porewater and surface water is expected to also reduce concentrations in dietary items through which fish and shellfish may be exposed to sediment-related contaminants.

RAO 2. Reduce human health risks associated with exposure to COCs through direct contact with sediments and incidental ingestion to protective levels by reducing sediment concentrations of COCs.

The *HHRA* contained estimates of unacceptable cancer risks associated with direct contact and incidental sediment ingestion in intertidal sediments of the Site during clamming by tribal members or playing on the beach, and in subtidal and intertidal sediments during netfishing. The risk drivers for the direct contact scenarios are arsenic, cPAHs, and dioxins/furans. Reducing the excess cancer risk for the clamming and beach play exposure pathways would entail reducing the contaminant concentrations in intertidal sediment to risk-based levels or background. Human exposure to the COCs for the clamming and beach play exposure pathways may occur within the upper few feet of sediment, depending on the activity. Deeper sediments will not contribute appreciably to these risks unless they are exposed in the future. Achieving and maintaining this RAO may include addressing deeper sediments that contain these contaminants if they are potentially subject to exposure over time as a result of erosion of the overlying sediments. Because children dig holes in beaches and some clams may burrow to depths of 45 centimeters or more, a depth of 45 centimeters is considered protective for the direct contact RAO for beach play and clamming scenarios. Remediation of clam beds should be of sufficient depth to provide clean, suitable substrate for the clams to live in.

Reducing risks to netfishers would entail reducing sitewide average contaminant concentrations in subtidal and intertidal sediment. Exposure to the COCs for the

netfishing exposure pathway would occur to sediment at and near the sediment surface. Deeper sediments will not contribute appreciably to these risks unless they are exposed in the future. Achieving and maintaining this RAO would include addressing surficial sediments.

RAO 3. Reduce risks to benthic invertebrate organisms by reducing surficial sediment concentrations of COCs to protective levels.

The *ERA* concluded that ecological risks were estimated to be above regulatory thresholds for the benthic invertebrate community. The *ERA* identified arsenic, copper, mercury, and total PCBs as risk drivers for the benthic invertebrate community, based on exceedance of Washington CSLs, and other contaminants as COCs based on exceedances of SQS or surrogate sediment quality guidelines where SQS are not available. Washington State SMS are ARARs for the Site (see Section 9.2). The goal of the SMS is to achieve the SQS level, and any sediment cleanup standard between the SQS and CSL is contingent upon site-specific conditions, practicability, and attainment of cleanup standards in a reasonable timeframe (generally specified in the SMS as 10 years). Achievement of this RAO is determined on a point basis and can be demonstrated through comparison to the SQS or by toxicity testing showing no adverse affects.

Exposure of benthic organisms to COCs occurs within the biologically active zone, which is generally defined in the Puget Sound Estuary Program Protocols and Puget Sound Ambient Monitoring Protocols and in the Sediment Sampling Analysis Plan Appendix (Ecology, 2003) as the upper 10 centimeters of sediment in Puget Sound. Deeper sediments will not contribute appreciably to these risks unless they are exposed in the future. In some areas, achieving and maintaining this RAO may therefore include addressing deeper sediments that contain these risk drivers if they are potentially subject to exposure as a result of erosion or other forces that may disturb the overlying sediments.

RAO 4. Reduce risks to crabs, fish, birds, and mammals from exposure to COCs by reducing concentrations of COCs in sediment and surface water to protective levels.

Note: Expected improvements to surface water quality and reduction of any potential risks to fish and wildlife will be achieved through remediation of site sediments; no active remediation of surface water will be conducted.

The *ERA* identified risks to crabs, fish, and shore birds exposed to bioaccumulative chemicals in site sediments. The COCs identified were those contaminants with exposure concentrations or doses to the receptors exceeding LOAEL-based TRVs. One COC was identified as a risk driver for crabs for which a sediment RBTC was developed. Three COCs were identified for fish and two for sandpiper in intertidal sediment. Risks to predatory birds and river otter or other mammals were not quantitatively assessed in the *ERA* (see Section 7 of this document). Achievement of RAO 4 is based on addressing risks to all of the fish and wildlife receptors based on a sitewide basis. For crab, risks are associated with concentrations of TBT in sitewide surface sediment; for fish, risks are associated with concentrations of copper, TBT, and total PCBs in sitewide sediment; and for sandpiper, risks are associated with sitewide concentrations of copper and lead in intertidal sediment. The majority of risks to crab, fish, and shore birds are associated with sediment contaminants that have been taken up by prey items, such as benthic invertebrates and smaller fish. Reduction of concentrations of COCs in the upper layers of sediment will help reduce concentrations of COCs in prey tissue that may occur through direct contact with sediment and will also reduce the transfer of COCs to sediment porewater and to surface water, which may also be a source of contaminants to prey tissue. Reducing concentrations of COCs that may transfer to porewater and surface water is expected to reduce concentrations in prey items through which crab, fish, predatory and shore birds, and mammals may also be exposed to sediment-related contaminants. The potential for exposure of small fish and benthic invertebrate prey to COCs occurs primarily within the upper 10 centimeters of sediment. Covering these surficial sediments would reduce exposures and risks to organisms that may inadvertently consume them and to organisms that consume prey exposed to chemicals in the surficial sediments.

For all of these RAOs, unacceptable concentrations of COCs in subsurface sediments beneath the biologically active zone may present a concern for potential risks if they can be exposed due to

deeper bioturbation, erosion of surface materials, or other disturbances. Although an important consideration, erosion is not the only mechanism that can expose deeper, contaminated sediments to the surface and contribute to risk. Deeper, contaminated sediments may be reworked by scour from prop wash or tug or barge scour. Current and potential future maritime activities are taken into consideration in determining whether subsurface sediments are addressed by remediation. Subsurface sediments known to be contaminated will be isolated from exposure after implementation of the active remediation planned for the Lockheed West Site.

The focus of the preliminary RAO development is the impact of the contaminated sediments on human health, the benthic invertebrate communities, and ecological receptors that use the Site. The preliminary RAOs may be refined and updated as additional Site information is collected as part of the remedial investigation. While the RAOs define the narrative intent that any remedial actions that may be undertaken to address these risks will need to meet, numerical PRGs are required to support the evaluation of remedial alternatives for the Site. Such PRGs define the concentrations of COCs in the affected media that correspond to the RAOs (i.e., that will be protective of ecological and human health receptors). Development of PRGs is discussed in Section 9.4.

9.3.2 Source Control

In addition to the above four RAOs, source control plays a role in achieving the RAOs by minimizing the potential for post-cleanup recontamination of the Lockheed West Site sediments. Implementation of effective source control measures is implicit in achievement of all of the aforementioned RAOs. An adequate level of source control is an assumed element of remedial design and implementation planning, which will preclude unacceptable levels of recontamination during or following the remediation of contaminated sediment areas. Source control is generally defined as “those efforts taken to eliminate, or reduce, to the extent practicable, the release of contaminants from direct and indirect continuing sources to the water body under investigation” (EPA, 2005b).

The Site is no longer an active shipyard and the upland area has been remediated and developed; thus, the sources of contamination from upland soils have been controlled to the extent practicable. For example, the *Source Control Evaluation Report* found relatively low likelihoods

of remedy recontamination for multiple potential sources, including the following: stormwater discharges from the SW Florida Street Outfall, the former shipyard uplands various sources, and the current property at Terminal 5; from overwater uses such as spills; from CSO discharges; from wastewater discharges; and from atmospheric deposition.

It was also noted in the *Source Control Evaluation Report* (Section 3.3.6) that contaminated groundwater discharges from the former shipyard uplands presents a relatively low likelihood of remedy recontamination based on the most recent groundwater data collected from the former shipyard uplands and the relatively large distance to the Lockheed West Site from the PSR upland site. The most recent groundwater contaminant concentration data for select PAHs and arsenic collected from four wells in 2008 at the former shipyard uplands (presented in Appendix E2 of the *Source Control Evaluation Report*) were found to be below both SQS and natural background values in sediment when they were converted to water reference concentrations based on equilibrium partitioning. Although arsenic concentrations were found to be below the water reference concentrations for SQS and natural background, the concentrations exceeded the water reference concentration based on the RBTC for tribal RME seafood consumption. However, arsenic concentrations in all four wells are within the range of arsenic background concentrations for groundwater determined for the SWHP and thus arsenic is considered to present a low likelihood for recontamination.

For PSR contaminated groundwater, the conclusion presented in the *Source Control Evaluation Report* was that there is uncertainty about the potential for PSR groundwater to be a source of recontamination to the Lockheed West Site sediment. Recent PSR groundwater monitoring results show potential seaward migration of dense non-aqueous phase liquid and dissolved contamination in groundwater near the western boundary of the former shipyard uplands. This finding resulted in the recent EPA 5-year review finding for the PSR site (EPA, 2009e) that deferred a determination of long-term remedy protectiveness. The EPA continues to evaluate the remedial action at the PSR site and will evaluate its protectiveness with respect to source control at the Lockheed West Site.

Despite existing controls over original sources of contamination to the Site, there are ongoing sources that have the potential to recontaminate sediment cleanup at the Lockheed West Site

(Tetra Tech, 2009a,b). Deposition of sediment from the West Waterway and farther upstream in the Lower Duwamish Waterway and from Elliott Bay, has a high likelihood of contributing recontamination to the Site at concentrations above the RBTCs and natural background concentrations (Tetra Tech, 2009b). This conclusion is based partly on cap monitoring results at the LSSOU site on the east side of the West Waterway, which suggest that there is an ongoing transport and deposition of sediment in the general area that is likely to recontaminate the Lockheed West Site remedy at concentrations above the RBTCs and natural background concentrations. Substantial efforts at source control are ongoing in the upstream LDW that could eventually reduce upstream contributions (AECOM, 2009). Potential sources to the Lockheed West Site have recently been evaluated and control efforts identified (Tetra Tech 2009b). In addition to controlling sources of contamination to Site sediments, source control is important to improve water quality in the West Waterway and Elliott Bay areas of the Site. Because potential sources of remedy recontamination are outside of Lockheed Martin's control, are related to the surrounding area, and are required to be addressed through multiple regulatory programs and entities, the objective of controlling sources is not included in the detailed descriptions of RAOs.

9.3.3 Potential Remedial Alternatives

Potential remedial alternatives for the Lockheed West Site were identified in the *RI/FS Work Plan* based on Site conditions, estimated human health and ecological risks, and the precedent set for the upstream LDW. It was concluded in the draft LDW RI (Windward, 2008) that RBTCs for PCBs and other carcinogens are lower than cleanup levels mandated under the Washington State SMS (WAC 173-204) for protection of benthic invertebrate communities, and are likely lower than natural background levels. Given this finding, Lockheed Martin concluded that No Action and natural recovery remediation alternatives at the Lockheed West Site were unlikely to meet risk-based cleanup levels and that active remediation alternatives would be required to achieve a final remedy. The current commitment by Lockheed Martin to achieve a final remedy through active remediation of the Site may consist of placing covers over contaminated sediments identified in the RI as presenting human health or ecological risks above regulatory thresholds. Other remediation approaches, such as dredging, may also be implemented if Site conditions warrant their use.

9.4 PRELIMINARY REMEDIATION GOALS

Preliminary remediation goals are the contaminant endpoint concentrations associated with each RAO that are believed to be sufficient to protect human health and the environment based on available site information (EPA, 1997c). The PRGs are used in the FS to guide the evaluation of proposed sediment remedial alternatives but they are not the final CERCLA cleanup levels; EPA will ultimately define those levels in the ROD. This section summarizes the PRGs developed in the *RAO Memorandum* that would be used by EPA to determine sediment cleanup levels and performance criteria for the Lockheed West Site.

While RAOs define the narrative intent that any remedial actions will need to meet, numerical PRGs are often required to support the evaluation of remediation alternatives for a site. Numerical PRGs define the concentrations of COCs in the affected media that correspond to the RAOs (i.e., that will be protective of human health and ecological receptors on the Site). Numerical PRGs for the Lockheed West Site consist of chemical-specific ARARs, RBTCs, background concentrations, and PQLs. For each RAO and COC, the PRG would typically be selected as the lowest value among the ARARs and RBTCs. However, where RBTCs are below background for a given contaminant of concern, the background value would be selected; where RBTCs and background are below the PQL for the COC, the PQL would be selected.

Per EPA guidelines, PRGs are intended to be based on a combination of ARARs and the RAOs that are designed to minimize risks to human health and the environment. As presented in Section 9.2, the key ARARs for this project include the Washington State SMS, Clean Water Act, Model Toxics Control Act (MTCA; WAC 173-340), and the Rivers and Harbors Act.

Narrative RAOs for the Site are presented in Section 9.3.1. Numerical PRGs for the Lockheed West Site have been developed based on the following sources:

- **Background Concentrations** for COCs with ARARs or RBTCs less than background;
- **ARARs**, including Washington State SMS and MTCA;
- **Risk-Based Concentrations**, SMS for benthic invertebrate communities and RBTCs for human and ecological receptor exposures; and
- **Practical Quantitation Limits** for COCs without background levels and with RBTCs less than PQLs.

The final cleanup level for each COC in intertidal and subtidal sediments of the Site will consist of one of these numerical PRGs. The following describes how each of these sets of PRGs was determined for the Lockheed West Site.

9.4.1 Determination of Background Concentrations

Given the urban and industrial location of the Site, determining background sediment concentrations has been an ongoing challenge for the RI/FS. The following discussion presents a summary of the regulatory framework and potential data sets that can be used to help define background concentrations.

Under CERCLA, background contaminant concentrations are considered when formulating PRGs and cleanup levels and recognizes that setting numerical cleanup goals at levels below background is impractical. Both EPA and Ecology recognize two types of background—natural and "anthropogenic" (EPA) or "area" (Ecology)—although their definitions and uses differ. The most important difference is in the potential application of anthropogenic or area background concentrations in making risk management decisions. Both CERCLA and MTCA guidance regarding derivation and use of background concentrations are followed, because MTCA is considered an ARAR for the Site. Under MTCA, natural background is considered one of the sources of PRGs for the Site. In general, EPA does not require cleanup levels below anthropogenic background concentrations because of the potential for recontamination from sources unrelated to the site, cost effectiveness, and technical practicability (EPA, 2002b).

9.4.1.1 Definitions and Uses of Background in CERCLA Cleanup

According to CERCLA guidance, natural background refers to substances that are naturally present in the environment in forms that have not been influenced by human activity (e.g., naturally occurring metals). The CERCLA guidance states that natural background concentrations establish a limit below which a lower cleanup level cannot be achieved (EPA, 2005b). It is also recognized in CERCLA that natural and human-made contaminant concentrations can occur at a site not as a result of local site-related releases but as a result of human activities in areas remote from the site and natural processes that transport the contaminants to the site (e.g., atmospheric uptake, transport, and deposition). "Anthropogenic background" is defined by CERCLA as natural and human-made substances present in the

environment as a result of human activities, but not related to a specific release from the CERCLA site undergoing investigation and cleanup (EPA, 2002b). Although CERCLA generally does not require cleanup to concentrations below anthropogenic background levels (EPA, 1996, 1997b, 2002c), Section 121(d)(2)(A) of CERCLA generally provides that remedial actions shall meet ARARs, unless those requirements are waived pursuant to section 121(d)(4) under appropriate site-specific circumstances. EPA may work with other agencies to develop a comprehensive approach to contaminants with significant anthropogenic background levels of contamination (EPA, 1997b). Application of anthropogenic background in risk management decision-making is recognized by EPA as a means to minimize the risk of recontamination from sources outside of those related to the site.

Under CERCLA, anthropogenic background concentrations are generally higher than natural background concentrations because the former are more inclusive of urban environments. The highly developed industrial and urbanized environment surrounding Elliott Bay and the West Waterway, along with various land uses and human influences in the watershed upstream of the Site (e.g., the West Waterway, LDW, and industrial areas that lie upstream of LDW), could strongly influence the long-term attainment of natural background for the Lockheed West Site.

Various approaches for determining background concentrations for evaluation as cleanup levels were introduced in the *RI Work Plan*, recognizing that selection of background values will be an ongoing process throughout the RI. The final approach for determining background for the Site will be identified after consultation with EPA and stakeholders. Preliminary approaches can be identified as the following and are discussed further below:

- **Natural Background Values –** Natural background values are identified as sources of PRGs for the Site. Comments from EPA on the *Nature and E xtent Sum mary Memorandum* identified the recent EPA (2009a) "Bold Study" survey as an appropriate source for natural background levels of contaminants. The EPA "Bold Study" survey is used herein as a source of natural background values for Lockheed West Site contaminants.
- **Use of the LDW Background Values –** EPA and Ecology have determined that anthropogenic background values for LDW will consist of upstream Green River data. However, EPA has neither applied statistical analysis nor determined the appropriate statistics to use to identify specific anthropogenic background values from these data sets.

At present, EPA has developed preliminary background values for areas influenced by human activities that are documented in the draft LDW FS and project meetings (LDWG, 2010), based on data collected from intra-site data and upstream of the site (AECOM, 2009). Because statistical analyses have not been performed or approved by EPA or Ecology for determining anthropogenic background, the values presented by the Lower Duwamish Working Group in the draft LDW FS are considered provisional anthropogenic background values. These provisional values are identified herein as potentially provisional anthropogenic background for the Lockheed West Site.

9.4.1.2 Natural Background

Natural background values for the Site have been identified based on comments from EPA on the *Nature and Extent Summary Memorandum* from the 2008 "Bold Study" (EPA, 2009a). Because the "Bold Study" was a robust study and did not have the problems associated with earlier studies (such as high detection levels, multiple study purposes and areas, and varying data quality), the "Bold Study" data set was identified by EPA and Ecology as the primary data set for defining natural background, except as noted below.

As per EPA (2009a), the "Bold Study" was conducted "in order to provide background data on dioxins/furans and PCBs that may be necessary to evaluate the practical, economic, environmental, and consequences of regulatory guideline alternatives being considered." As part of the background sediment data set, the "Bold Study" included all SMS chemicals. The full data set was considered to represent background as supported by the finding that there were no statistical differences in the TEQs for dioxins/furans or PCBs between identified reference areas and the greater Puget Sound data set. For arsenic, development of a natural background value is to include consideration that the "Bold Study" sampling locations were not screened for location relative to arsenic smelters in Everett, Tacoma, or elsewhere. For PCBs, Aroclor data were all non-detect in the "Bold Study" and therefore cannot be used to develop natural background for total PCBs. Because of the lack of PCB congener data at the Lockheed West Site, the development of natural background values for individual PCB congeners would not be useful. Instead, the total PCB congener data from the "Bold Study" are used to develop a natural background value for total PCBs in sediment, to which total PCBs based on Aroclor data at the Lockheed West Site are compared.

9.4.1.3 Anthropogenic Background

Two datasets of anthropogenic background data may be applicable to the Lockheed West Site: values provided by EPA as provisional anthropogenic background from the Green River, and values derived from an Ecology data set from Elliott Bay sediments.

9.4.1.4 EPA Provisional Anthropogenic Background

The EPA-provided provisional anthropogenic background concentrations for total PCBs, arsenic, cPAHs, and dioxins/furans (EPA, 2007b) were originally reported in the draft LDW FS (AECOM, 2009). The values calculated by EPA are considered draft or provisional and are repeated herein as potential values for anthropogenic background for the Lockheed West Site. The values come from the upstream Green River, which has been identified as an appropriate area by EPA for anthropogenic background data for LDW. The study was conducted to investigate loading of contaminants associated with suspended sediment in the Green River to LDW. Only data for arsenic, PCBs, and cPAHs are available.

EPA evaluated four sources of data for anthropogenic background concentrations for the four risk-driver chemicals at LDW:

- Concentrations on total suspended solids in the upstream Green/Duwamish River (upstream of RM 5.0),
- Concentrations on surface sediments collected in the upstream Green/Duwamish River,
- LDW core data collected from RM 4.0 to RM 4.75 (Upper Turning Basin at the upstream end of the LDW), and
- LDW surface sediment data collected from RM 4.0 to RM 4.75.

The EPA-derived provisional anthropogenic background values were reported as means of the 95 UCL of values:

- Total PCBs: 53 µg/kg-dw
- Arsenic: 9 mg/kg-dw
- cPAH: 151 µg TEQ/kg-dw.

In subsequent comments on the draft LDW FS (AECOM 2009), EPA and Ecology (2009) further clarified the data sets to be used for determining anthropogenic background values:

- 2008 upstream data collected by Ecology (including recently analyzed archived samples), but an outlier value of 770 µg/kg PCBs was removed because it appears to be related to an outfall;
- Suspended sediment data from the Ecology study, but with considerations for averaging since they represent loading values during various flow and rainfall events; and
- USACE turning basin sampling data for RM 4.5 to 4.75 of the LDW, excluding 1989 data, if it is shown that these data are not influenced by sources.

Note that these data sets differ from the ones that EPA (2007b) originally used to calculate provisional anthropogenic background values. The EPA and Ecology have not recalculated anthropogenic background values for LDW using the clarified data sets. The EPA provisional anthropogenic background values are subject to revision using the above recommended data sets.

Provisional anthropogenic values for the LDW were updated in a handout of a presentation by the Lower Duwamish Waterway Group to project stakeholders on January 22, 2010 (LDWG, 2010). These updated anthropogenic background values are only available for LDW risk-driver COCs and are included in Table 9-3 in this section.

9.4.1.5 Elliott Bay Data

Under the Urban Waters Initiative, Ecology (2009a) collected data on sediment contaminant concentrations in three anthropogenic-use/geomorphological areas of Elliott Bay: deep basin, urban/mid-bay, and harbor/inner bay. The areas for sampling were originally identified as part of the 1997-1999 joint NOAA-Ecology sediment survey called Puget Sound Ambient Monitoring Program/NOAA, which was conducted as part of NOAA's National Status and Trends Program and the Puget Sound Ambient Monitoring Program. The sampling locations consisted of 2 deep basin stations, 15 harbor/inner bay stations, and 13 urban/mid-bay stations (Figure 9-1). The sampling locations and data results are summarized in the Ecology (2009a) report. Sample collection methods followed the Puget Sound Estuary Program Protocols (PSEP 1986).

The data from the three Elliott Bay anthropogenic-use areas are explored as potential sources of data to represent anthropogenic background along the northern and eastern borders of the Lockheed West study area along Elliott Bay and West Waterway. The data from the harbor/inner bay may be influenced by nearby point sources. The 95 UCL values for the three data sets were

determined using ProUCL version 4.00.02. The 95 UCL values for these three data sets are included as anthropogenic background values in Tables 9-3 and 9-4 for those chemicals for which data are available. The ProUCL calculation outputs are included in Appendix A.

9.4.1.6 Comparison of Background Data Sets

The various background data sets identified above as potentially applicable to the Lockheed West Site are compared in Figures 9-2 and 9-3. The mean, minimum, and maximum concentrations of select COCs are presented as bar graphs in Figure 9-2 for metals and in Figure 9-3 for organic compounds. None of the data sets were truncated to remove potential outliers; data were used as presented in the original source.

The comparisons in Figures 9-2 and 9-3 illustrate the similarity among the background data sets for Elliott Bay and the anthropogenic values previously identified for the upstream LDW site. The natural and provisional anthropogenic background values and the Elliott Bay urban, harbor/inner bay and deep basin values are presented as background values in Tables 9-3 and 9-4, which summarize the range of potential PRGs for the Site COCs.

9.4.2 Key ARARs

This section evaluates key ARARs considered in the determination of PRGs, including the state sediment quality standards, state hazardous waste cleanup rules, and surface water quality standards.

9.4.2.1 Washington State Sediment Management Standards

The ARAR that influenced the selection of numerical sediment PRGs for the Lockheed West Site is the Washington State SMS (WAC 173-204). The SMS provide a basis for the management and reduction of pollutant discharges and guide contaminated sediment cleanup efforts. They include regionally-developed numerical sediment criteria that protect the benthic invertebrate community (and hence the SMS criteria apply to RAO 3). Following are the two primary types of SMS related to benthic invertebrate protection: source control standards, which define the maximum degree of sediment contamination allowed in sediments impacted by ongoing discharges; and screening standards, which indicate the maximum degree of sediment contamination allowed before an evaluation of contamination is required. The SMS also include

a narrative standard that sediment cleanups should be protective of human health; in this case, based on a risk assessment approach. These risk-based standards may be applied on different scales (i.e., sitewide vs. point). The benthic invertebrate numerical criteria are not intended to be protective of human health with regard to consumption of bioaccumulative contaminants in seafood.

The benthic invertebrate SMS define two levels of chemical and biological standards. The more stringent level, the SQS, is the sediment cleanup objective and corresponds to a sediment quality that has no acute or chronic adverse effects on benthic marine organisms. The less stringent level, the CSL, is the level above which minor adverse effects are likely to occur in benthic marine organisms. The biological standards are based on results of biological tests that demonstrate adverse effects in benthic organisms that dwell in sediments. If both biological and chemical data are obtained at a site, the biological data determine compliance with the SMS.

According to the SMS, sediment cleanup standards for benthic invertebrates are established on a site-specific basis (WAC 173-204-570). The site-specific standard must be between the SQS, which is the cleanup objective, and the CSL, also known as the minimum cleanup level. Sediment cleanup standards must be as close as practicable to the SQS as per WAC 173-204-570(4). For the purposes of developing PRGs and analyzing alternatives for all benthic invertebrate community COCs at the Lockheed West Site, the lower end of this range (i.e., the SQS) is used. The SQS criteria are identified as risk-based numerical PRGs for benthic invertebrate COC risk drivers and non-risk drivers in Tables 9-3 and 9-4, respectively. The SMS criteria are applied on a station-specific basis to the biologically active zone of the sediments (i.e., upper 10 centimeters). For consistency with LDW, their application as PRGs is identified as a “Point” basis in Tables 9-3 and 9-4 to denote their application to individual sediment stations rather than to an area-wide average.

9.4.2.2 State Hazardous Waste Cleanup Rules

Washington State has promulgated environmental regulations to implement several major federal programs; in cases where the state requirement is more stringent that the federal requirement, the state requirement is an ARAR. There are no federal regulations providing numerical standards

for chemicals in sediment. However, Washington State has promulgated numerical standards in the SMS and these regulations are cross-referenced in MTCA (refer to Section 9.4.2.1).

The SMS does not address the method for determining sediment background concentrations, and Washington State is currently considering additional rule making to address acknowledged inconsistencies between MTCA and the SMS (Ecology, 2009b). Under MTCA, background includes natural and area-wide definitions as follows (WAC 173-340-200):

- **"Natural Background**" *means the concentration of hazardous substance consistently present in the environment that has not been influenced by localized human activities. For example, several metals and radionuclides naturally occur in the bedrock, sediments, and soils of Washington state due solely to the geologic processes that formed these materials and the concentration of these hazardous substances would be considered natural background. Also, low concentrations of some particularly persistent organic compounds such as polychlorinated biphenyls (PCBs) can be found in surficial soils and sediment throughout much of the state due to global distribution of these hazardous substances. These low concentrations would be considered natural background. Similarly, concentrations of various radionuclides that are present at low concentrations throughout the state due to global distribution of fallout from bomb testing and nuclear accidents would be considered natural background.*
- "**Area Background**" *means the concentrations of hazardous substances that are consistently present in the environment in the vicinity of a site which are the result of human activities unrelated to releases from that site.*

MTCA defines natural background as the cleanup standard required for final remedies when natural background concentrations are higher than the calculated risk-based cleanup levels. Under MTCA, a remedy that cannot achieve natural background concentrations is not considered final. For the LDW cleanup, a joint EPA and state-lead site being conducted under CERCLA and MTCA, EPA has determined that this aspect of MTCA is an ARAR under CERCLA and that natural background values as defined in the "Bold Study" are appropriate as PRGs. The EPA has also indicated that a similar approach regarding natural background be adopted for the Lockheed West Site.

The use of natural background concentrations as a sediment cleanup level for selected COCs (i.e., PCBs, cPAHs, arsenic) is problematic in this industrial setting because it is impractical to

achieve these levels. For this reason, EPA Superfund and sediment cleanup guidance does not support adoption of cleanup levels below anthropogenic background in industrial settings. As documented in Section 5.0, there is also a high probability of remedy recontamination at these very low concentrations.

A waiver of the MTCA requirement for use of natural background for cases in which the RBTC is lower than natural background (i.e., PCBs, cPAHs, arsenic) will be necessary for successful implementation of the cleanup action. Under the NCP, EPA has the ability to waive an ARAR, including aspects of a state environmental law (e.g., MTCA) at the time of the ROD under specific circumstances (40 CFR 300.430: 7-1-00 Edition). These waiver provisions include the following:

- **Technical impracticability.** The EPA has acknowledged that achievement of natural background cleanup levels is impracticable if not impossible under current conditions.
- **Inconsistent application of the state standard by the state**. Natural background or RBTCs are the basis for determining PRGs based on MTCA. Alternate background levels and other tribal framework considerations are outside of current MTCA regulatory considerations for establishing permanent cleanup levels. Ecology is currently considering additional rule-making to address acknowledged inconsistencies between MTCA and the SMS (Ecology, 2009b). The natural background standard has not been consistently applied because it is not specified in the Washington State SMS.

9.4.2.3 Surface Water Quality Standards

Surface water quality criteria have been identified by EPA as ARARs for the Site and included in RAOs 1 and 4 (refer to Section 9.3). As stated in the explanatory note to these RAOs, expected improvements to surface water quality will be achieved through the remediation of Site sediments; no active remediation of surface water will be conducted. Other sources have been identified that potentially affect water quality in the vicinity (e.g., overwater uses and spills, stormwater discharges, wastewater discharges, CSOs, upland contaminated sites, nearby sediment cleanup sites, atmospheric deposition; refer to Section 5). Similar to the LDW RI/FS, surface water is included as a medium of concern to be addressed by RAOs 1 and 4; however, surface water quality ARARs are not appropriate for use as numerical PRGs.

9.4.3 Risk-Based Concentrations

In the ROD, risk-based cleanup levels will be determined for the list of COCs identified in the human health and ecological risk assessments, except for dioxins/furans. The risk-based sediment cleanup levels will be derived from risk-based concentrations in sediment defined as acceptable concentrations for the primary exposure pathways of greatest risks, in accordance with EPA guidance. The risk-based concentrations are termed RBTCs in this document to be consistent with the terminology that is being used at the nearby LDW. The RBTCs are considered to be one of the refined numerical PRGs for the Site sediment, per EPA (1988) guidance. As risk-based PRGs, the RBTCs will form the basis for setting both risk-based cleanup levels for Site sediment and risk-based monitoring and/or performance criteria for post-remedy sediments and capping material.

9.4.3.1 Basis of Risk-Based Threshold Concentrations

Guidance in EPA (1999c) states that numerical RAOs based on the risk assessments should specify the following:

- COCs,
- Exposure pathway and receptors, and
- Acceptable contaminant level or range of levels for each exposure route.

The RBTCs for the Lockheed West Site are determined as concentrations for each COC in sediment that correspond to acceptable risk levels for each human health and ecological exposure pathway. The focus of the RBTC development is the protection of the exposure pathways of greatest risk for human activities and ecological receptors. Thereby, RBTCs for the exposures of greatest risk in a given exposure medium are protective of all other possible exposures appropriate for the Site under current and future conditions. Exposure pathways for human health and ecological receptors were identified and summarized in the risk assessments (Section 7.0).

For each COC, RBTCs are developed for each of the major exposure pathways for which data are available. This approach differs from the recent draft LDW RI (Windward, 2008), which developed RBTCs only for a subset of COCs identified as the risk drivers. For the Lockheed West Site, RBTCs are developed for all COCs based on assumed relationships between sediment and tissue that are modeled.

The major exposure pathways are defined as those presenting the greatest risk estimates in the baseline human health and ecological risk assessments. The exposure scenarios of relatively greater risk estimates will result in the most stringent (i.e., lowest cleanup level) when considering all populations of receptors that might undergo that exposure.

The RBTCs are concentrations in sediment associated with regulatory risk thresholds for human health and ecological receptors for the pathways and exposures identified earlier in Section 7. For the human-health risk assessment, excess cancer and non-cancer risks were estimated based on exposures as doses to sediment through direct contact, such as dermal contact or incidental ingestion, and through the ingestion of seafood that had taken up chemicals from the sediment of the Site. Ecological risks were determined based on the level of contaminant concentration exceedance of sediment criteria for benthic invertebrates or the level of dose or receptor tissue contaminant concentration exceedance of TRVs for fish, crabs, and birds. The PRGs for benthic invertebrates were identified above in Section 9.4.1 as SMS. The RBTCs for fish, crab, and birds are identified below.

Once the RBTCs are identified for the exposure pathways, the most stringent levels for intertidal and subtidal sediments are identified as the risk-based PRGs, which as one set of PRGs can be used to set risk-based cleanup levels. Subsequent to Site remediation, the risk-based PRGs could also be used as risk-based monitoring criteria.

9.4.3.2 Approach to Developing Risk-Based Threshold Concentrations

As described in the *RI/FS Work Plan* and the risk assessments for the Lockheed West Site, the human health exposure scenarios and ecological receptors selected for evaluation were deemed to be those most appropriate to represent RME for the environmental conditions and habitats at the Site. The RBTCs are developed for these human health RME scenarios and the ecological receptors.

For human health, the RBTCs are defined as concentrations for COCs associated with a 1×10^{-4}, 1×10^{-5}, and 1×10^{-6} cancer risk and an HQ of 1.0; for ecological receptors, the RBTCs are defined as the concentrations associated with an HQ of 1.0. For human health, the RBTCs are developed in sediment for the direct exposure scenarios of netfishing, beach play, and clamming; and in sediment for the indirect exposure scenarios of seafood consumption.

In the determination of sediment RBTCs for seafood ingestion, tissue concentrations in fish and clam tissue are developed that are associated with the regulatory acceptable risk levels based on tribal ingestion rates for those seafood categories. The tissue concentrations of chemicals that were used in the baseline risk assessments for the Lockheed West Site were modeled from sediment concentration because site data on tissue concentrations of COCs in the seafood categories are not available. Because sediments are the environmental medium of concern at the Lockheed West Site and will be the focus of site cleanup and Site tissue data are not available, RBTCs are developed for intertidal and subtidal sediments. As applied to meeting RAO 1 in particular, the sediment RBTCs relate to a reduction in tissue concentrations of COCs and are protective of human and ecological receptor exposures to tissues of organisms that have taken up chemicals from Site sediments.

Details of the modeling of tissue concentrations have been described in the *HHRA* and *ERA*. The relationships were developed from a review of available BSAFs from literature compilations and databases, and from results of the food web model for PCBs developed for LDW and regression equations developed from co-located sediment and benthic invertebrate tissue data from LDW. In addition, EPA developed BSAFs for metals based on site-specific data developed from LDW, which were used in an alternative estimation of seafood ingestion risks in an attachment to the *HHRA*. The literature BSAFs were specific to clams, crab, and fish, which made up the seafood categories that were modeled. If BSAF values for the seafood categories were unavailable, then benthic invertebrate values were used. Sediment RBTCs for the Lockheed West Site are developed for all COCs that were identified for the consumption of fish and shellfish in both the human health and ecological risk assessments.

An alternative BSAF for uptake of TBT into crab was developed from sitewide data collected from the LDW site, following the procedure that was used in the Lockheed West risk assessments to develop the BSAF for uptake of TBT into fish based on LDW site-wide data. This is different from the BSAF for TBT that was presented in the RAO memorandum for the Site (Tetra Tech, 2010a) where a surrogate BSAF was developed using data from the ERED database on non-crab species. Sitewide data from the LDW site for sediment are available as mean concentrations of TBT and mean TOC content in Table E.6.1-1 of Appendix E of the final RI report for the LDW site. The sitewide data on mean concentrations of TBT in crab tissues

from the LDW were taken from Table B.2-4 of the final human health risk assessment for the LDW site. The crab tissue data were from a mix of species, consisting of 11 Dungeness crab, 2 red rock crab, and 12 slender crab. Data on the lipid content of crabs were taken as mean values from the food web model for the LDW site (Table D.4-1 of Appendix D of the LDW RI). The alternative BSAFs for TBT used to develop RBTCs for the Lockheed West Site based on the LDW data (sediment dry weight normalized to TOC/tissue wet weight normalized to lipid) are 0.072 for crab edible meat and 0.115 for crab whole body.

The use of modeling for determining tissue concentrations in both the *HHRA* and *ERA* was not designed to be highly site-specific; the modeling parameters were not developed with site-specific data other than sediment chemistry data. Because the Site is planned to be fully remediated with no evaluation of natural recovery of sediments (a brief evaluation of natural recovery of sediments is included in the FS), the intent was to streamline the process for performing the risk assessments and for identifying risk-based PRGs. For this approach, the use of modeling for determining tissue concentrations of COPCs was deemed sufficiently health protective. This assumption entails some uncertainty because the evaluation of co-located clam and sediment chemistry data from the upstream LDW did not observe significant relationships for either arsenic or cPAHs (Windward, 2008), both of which are risk drivers for the Lockheed West Site.

Dioxin/furan data were not available for the human health risk assessment but, as noted in the *HHRA,* the seafood consumption risks related to dioxins/furans in sediment would likely have been unacceptable. In lieu of quantified risk estimates or sediment data, remediation of dioxin/furan in sediment at Lockheed West Site will be based on background concentrations.

9.4.3.3 RBTCs for Human Health Direct Sediment Exposures

For direct sediment exposures, RBTCs are developed for the following three scenarios:

- Tribal clamming at 120 days per year – intertidal sediment
- Child beach play – intertidal sediment
- Tribal netfishing – subtidal plus intertidal sediment.

For each of these scenarios, RBTCs in sediment are developed by back-calculation from the regulatory acceptable risk levels and the RME exposure parameters specific to each scenario used to estimate risks. The result is a sediment concentration associated with the regulatory risk level. Exposure parameters such as exposure duration, exposure frequency, dermal absorption, and sediment ingestion rates can be found in the baseline *HHRA*. The RBTCs calculated for the direct exposure scenarios are listed in Tables 9-3 and 9-4 for risk-driver COCs and non-risk driver COCs, respectively. For the clamming and beach play scenarios, because they both apply to intertidal sediment, only the lowest RBTC for either scenario is reported (e.g., arsenic for clamming, cPAHs for beach play).

9.4.3.4 RBTCs for Human Health Indirect Sediment Exposure: Seafood Consumption

In the human health risk assessment, the tribal seafood consumption pathway based on the Tulalip survey is the RME scenario with the greatest excess cancer and non-cancer risks for the Site. The sediment RBTCs for seafood consumption are sediment concentrations of COCs associated with seafood tissue concentrations at acceptable levels of risk based on seafood consumption. The seafood tissue concentrations are developed from regulatory risk thresholds and exposure parameters for tribal seafood consumption, including seafood ingestion rates. The sediment RBTCs are then calculated from the acceptable tissue concentrations using the mathematical relationships that relates contaminant levels in seafood with those in sediment.

The calculation starts with the regulatory risk thresholds of 10^{-4}, 10^{-5}, and 10^{-6} cancer risk and the non-cancer HQ of 1. Working backward through standard risk assessment equations, the regulatory risk level is factored in with the tribal RME consumption rate for various seafood categories, tribal body weight, and exposure frequency and duration, resulting in seafood tissue concentrations associated with the regulatory risk thresholds (i.e., the tissue RBTCs). All exposure factors are described in the *HHRA* for the adult tribal RME seafood consumption based on the Tulalip survey scenario. The tribal seafood consumption scenario based on the Suquamish survey was included in the *HHRA* to assist in characterizing the range of seafood consumption risks, as discussed in the *RI/FS Work Plan*, and not used to set cleanup levels for the Lockheed West Site. Thus, RBTCs were not derived for the Suquamish survey-based seafood ingestion scenario. Because of the higher seafood ingestion rates, RBTCs for the Suquamish survey-based

seafood ingestion scenario would be lower than those calculated for the Tulalip survey-based RME seafood ingestion scenario.

From these tissue concentrations, quantifiable tissue-to-sediment relationships, such as the BSAFs and regression relationships described above, were used to determine associated sediment concentrations. These sediment concentrations are the sediment RBTCs for the indirect exposure pathway of seafood ingestion. The RBTCs for COCs for the indirect exposure scenarios of tribal seafood ingestion are listed in Tables 9-3 and 9-4 for risk-driver COCs and non-risk driver COCs, respectively. Because cancer risks for the adult tribal RME seafood ingestion scenario were higher than for the child scenario, RBTCs are reported for the adult scenario. For non-cancer HQs, the child tribal RME seafood ingestion scenario presented higher risks than for adults for all COCs, so RBTCs are presented for non-cancer risks only for the child tribal seafood ingestion scenario.

9.4.3.5 RBTCs for Ecological Receptors

The RBTCs for ecological receptors are developed from the types of receptors, their habitat exposures, and their exposures directly to sediment and through the food chain. The ecological receptors and exposure pathways that were evaluated in the *ERA* consisted of the following:

- Benthic invertebrate community, including clams – exposure to subtidal and intertidal sediment
- Crabs – evaluated based on levels in crab tissue, exposure is to food items and subtidal and intertidal sediment
- Fish (English sole, Pacific staghorn sculpin) – exposure to benthic invertebrates, crab, and lower trophic fish prey, and to subtidal and intertidal sediment
- Birds (spotted sandpiper) – exposure to benthic invertebrate prey and intertidal sediment.

The PRGs for benthic invertebrates consist of the Washington State SQS or other criteria that serve as surrogates where SQS are unavailable. Because they are toxicity-based values, the benthic invertebrate criteria can also be considered RBTCs for that receptor group. For fish and crab, RBTCs are those concentrations in sediment associated with the LOAEL-based HQ greater than 1. For crab, the HQ is calculated based on comparison of tissue concentrations with a tissue-based TRV that relates to the LOAEL. For fish, the HQ depends on the nature of the chemical,

whether the TRV is available as a tissue residue value or as a dietary dose to the fish. Thus, two types of RBTCs are developed for fish, one associated with LOAEL HQ greater than 1 based on comparison of tissue concentrations with a tissue residue TRV, and a second LOAEL HQ greater than 1 based on comparison of a dose that is modeled to fish with a dose-based TRV. For the tissue-based RBTC, the fish tissue concentration is modeled as described above for the *HHRA* seafood consumption scenario; for the dietary-based RBTC, the dose to fish is based on ingestion of sediment and prey items, for which tissue concentrations are modeled from sediment.

The RBTCs for sandpiper were developed from LOAEL-based doses resulting in an HQ greater than 1 related to ingestion of intertidal sediment during foraging, plus doses related to concentrations of chemicals in benthic invertebrates ingested as prey items. The relationships between tissue contaminant concentrations in the benthic invertebrate prey were developed using the modeling described above for the *HHRA* seafood ingestion scenario, except that modeling parameters were specific to benthic invertebrates.

The RBTCs for benthic invertebrates and ecological receptors are summarized in Tables 9-3 and 9-4.

9.4.4 Practical Quantitation Limits

Preliminary remediation goals and cleanup levels that are based on acceptable levels of risk to human health or ecological receptors are for some analytes below the ability of the analytical laboratories to reliably detect them in sediment. The level of reliable detection of chemical concentrations in sediment is the quantitation limit for that chemical. The quantitation limit is a function of the analytical method, the characteristics of the sediment material that is being analyzed, and the particular COC.

Although CERCLA guidance uses the term quantitation “limit” (EPA, 1991a), the PQL is defined under MTCA as the “lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods.” The NCP allows that remediation goals may be modified based on “factors related to technical limitations such as detection/quantification limits for contaminants.” Where RBTCs or a background value may be below the PQL for a COC, the PQL would be identified as the PRG. The PQLs are provided in

Tables 9-3 and 9-4. PQLs were used as PRGs for some COCs (i.e., DDT, chlordanes). The method detection limits and reporting limits identified as PQLs in Tables 9-3 and 9-4 were taken from the Lockheed West QAPP for sediment analyses, provided as Appendix D in the *RI/FS Work Plan*. The method detection limits and reporting limits were selected from the analytical laboratories as the lowest available to best meet risk-based analytical concentration goals for the sediment data collection.

9.4.5 Preliminary Remediation Goals Selection and Use

The PRGs developed for the Lockheed West Site are numerical values to be used to complement the narrative RAOs. As such, they may be used as cleanup levels and post-cleanup monitoring criteria or criteria for measuring the performance of site remediation. The PRGs consist of the four sources of numerical values presented above and following:

- ARARs,
- Risk-based threshold concentrations,
- Natural background concentrations, and
- Practical quantitation limits.

ARARs were discussed in Section 9.2 above. Risk-based PRGs (i.e., RBTCs) were developed in Section 9.4.2 and in the *RAO Memorandum* based on protection of both human health and ecological receptors (benthic invertebrate community, fish, crabs, and sandpipers). The SQS and screening level values, from the SMS and DMMP, respectively, are the RBTCs for protection of benthic organisms. The PRGs have been identified for each of the COCs for each of the RAOs to protect human health exposure and ecological receptors evaluated in the risk assessments. For each RAO and COC, the most appropriate PRG can be identified as one of the four sources listed above.

Table 9-3 presents the range of potential PRGs for the risk-driver COCs for all of the human health RME scenarios and for ecological receptors that satisfy the four RAOs for the Lockheed West Site. Table 9-4 presents the range of potential PRGs for the remaining non-risk-driver COCs, most of which are COCs only for RAO 3, protection of benthic organisms. If a chemical was not identified as a COC for a particular human exposure scenario or ecological receptor, the chemical is identified in Tables 9-3 and 9-4 as “Not COC” and no PRG is identified.

The ARARs that provide numerical values for sediment PRGs consist of the SMS for benthic invertebrates. Some of the sediment PRGs identified in Tables 9-3 and 9-4 correspond to RBTCs developed herein, such as for seafood ingestion and direct contact for human exposures, and for the higher trophic ecological receptors such as crab, fish, and sandpiper. The RBTCs take precedence if they are lower than ARAR-based concentrations. The preliminary remediation goals include natural background values for COCs with RBTCs below background, and PQLs where RBTCs and natural background are below the PQLs (i.e., the COC cannot be reliably measured analytically at the RBTC or background concentration). Attainment of seafood consumption-based sediment PRGs for subtidal and intertidal areas will satisfy direct-contact PRGs for intertidal sediments, because the seafood consumption-based PRGs are lower.

For RAO 1, protection of human consumption of seafood, the calculated sediment RBTC for total PCBs is below background. Note that the total PCBs RBTC that was based on the LDW food web modeling could be calculated only for the 1×10^{-4} cancer risk threshold. In that model, the contribution of PCBs in water alone was high enough to result in risks for the adult and child tribal RME seafood consumption scenarios exceeding the 1×10^{-6} and 1×10^{-5} cancer risk thresholds even in the absence of any contribution from sediment. (Note that in Table 9-3, because of the high number of non-detects for total Aroclors in the “Bold Study” data, a natural background concentration for PCBs as total Aroclors was not available; therefore, a natural background value for PCBs was derived from the “Bold Study” data on PCB congeners.) Similarly, the calculated RBTCs for arsenic and cPAHs based on 1×10^{-6} excess cancer risk for the human health seafood consumption pathway (RAO 1) are below background levels. In addition, RBTCs could not be derived for dioxins/furans because data on sediment concentrations are not available and, based on analyses in the LDW RI/FS, RBTCs would most likely have been below background levels for the RME seafood consumption scenarios.

For RAO 2, the RBTCs are based on a 1×10^{-6} excess cancer risk level, developed for three exposure scenarios: netfishing, tribal clamming, and beach play. Because PRGs are applied for comparison with the statistical metric for Site data over a given exposure area, netfishing PRGs are applied sitewide, and clamming and beach play PRGs are applied to intertidal sediment only.

For RAO 3, the PRGs are the SQS from SMS and the screening level from the DMMP for chemicals lacking SQS. These PRGs are applied on a point-basis and require that the sediment concentration following remediation be below the PRG at each individual station location. Under the SMS, sediment cleanup standards are established on a site-specific basis within an allowable range of contamination. The SQS and CLS define this range for SMS, and the screening level and maximum level define this range for the DMMP. For the purposes of deriving PRGs and analyzing alternatives, the lower of the two chemical-specific criteria (i.e., SQS and screening level) have been selected as the concentration-based PRG for that chemical. However, the final cleanup standard will be set in consideration of the CERCLA evaluation criteria and the analogous SMS considerations of net environmental effects, cost, and engineering feasibility of different cleanup alternatives under MTCA (WAC 173-204-570[4]).

For RAO 4, the ranges of PRGs are developed as RBTCs for fish, crab, and sandpiper, based on a hazard quotient of 1. For fish and crab, PRGs are applicable sitewide; for sandpiper, PRGs are applicable to intertidal sediments.

From the ranges of potential PRGs presented in Tables 9-3 and 9-4, single numerical PRGs are selected for each RAO. The results are summarized in Tables 9-5 and 9-6. The single numerical PRGs for RAOs 1 and 2 in Tables 9-5 and 9-6 are identified as the RBTCs unless the values are below background; in that case, the natural background is selected or, in the case of organochlorine pesticides, the PQL is selected in lieu of background. For total PCBs, arsenic, and cPAHs in Table 9-5, natural background values are selected as the PRGs to satisfy RAO 1 for protection of seafood consumption sitewide and from consumption of clams in intertidal sediments. The PRG for dioxins/furans is also selected as natural background for RAOs 1 and 2. For RAO 3, the PRGs are selected as the lowest of the range of sediment criteria, which consist of SQS for most COCs. For RAO 4, PRGs are selected as the lower of the RBTCs for fish and crab for sitewide exposures; for intertidal exposures, the RBTC for sandpiper is selected. Although not carried forward as a PRG, the anthropogenic background levels are considered in the development of the Site remedial action levels as discussed in Section 11.

The PRGs for each RAO and COC in Tables 9-5 and 9-6 are applied on either a point or sitewide basis, depending on the chemical, exposure pathway, and receptor of concern. The PRGs for

RAOs 1, 2, and 4 are applied on a sitewide average basis or an intertidal average basis. The PRGs applied on an area basis, both sitewide and for intertidal sediments only, require that the average sediment concentration over the applicable exposure area be below the PRG. The PRG is applied as an average concentration throughout the Site and is not applied to an individual point. For the average sediment concentration, the statistical metric used to compare post-remediation site data to the PRG is the 95 UCL on the mean sediment data, to be consistent with EPA guidelines on quantifying average concentrations. For sitewide exposures, the 95 UCL is used for the combined subtidal and intertidal sediment areas; for intertidal exposures, the 95 UCL is used for the intertidal sediment data alone. Because an unbiased sampling grid was used to collect the sediment data for the RI, the application of PRGs on an area-wide basis does not require spatial weighting, as spatial weighting is often used to reduce the impact of biased sampling. Instead, comparison of Site data with PRGs on an area-wide basis can use the 95 UCL on the mean concentration value. Use of the 95 UCL value is consistent with the method used to estimate exposures to sediment contaminants in the human health risk assessment and to ecological receptors other than benthic invertebrate communities in the ecological risk assessment.

The PRGs for RAO 3 are applied on a single point basis, where concentrations at each single location would have to meet the point-based PRGs. The PRGs are the SQS or a surrogate value (e.g., LAET) that is applied to a single sediment point, consistent with the application of SQS under Washington State SMS. For all COCs for RAO 3 in Table 9-5 and most of the metal COCs in Table 9-6, these point PRGs are applicable throughout the site to both subtidal and intertidal sediments. However, Table 9-6 identifies many non-risk-driver COCs (e.g., antimony, selenium, pentachlorophenol, bis[2-ethylhexyl]phthalate, and all of the PAHs) for which the point PRGs are applicable only to subtidal sediments because the chemicals were not identified as COCs for intertidal sediment.

The PRGs identified in Tables 9-3 and 9-4 and summarized in Tables 9-5 and 9-6 may be refined before the FS is finalized. Final cleanup levels will be determined by EPA in the ROD.

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Table 9-1.

Applicable or Relevant and Appropriate Requirements for the Lockheed West Site (Page 1 of 2)

Topic	Standard or Requirement	Regulatory Citation		ARAR Category C (Chemical-specific), A (Action-specific), and/or L (Location-specific)	Project-Specific Comments
		Federal	State or Local		
Sediment Quality	Sediment quality standards, cleanup screening levels	NA	Sediment Management Standards (WAC 173-204)	C	Numerical standards for the protection of benthic marine invertebrates. SMS is used in the development, analysis and selection of remedial action alternatives. Final remedy will meet requirements of the SMS.
Groundwater	Cleanup levels for groundwater	Safe Drinking Water Act MCLs and non-zero MCLGs (40 CFR 141)	RCW 43.20A.165 and WAC 173-290-310	C, L	Groundwater at adjoining former shipyard uplands is not part of the Lockheed West Site and is being cleaned up under MTCA by Port of Seattle as part of the Southwest Harbor Cleanup and Redevelopment Project. There is no potable water at the Lockheed West Site.
Surface Water Quality Standards	Surface water quality standards	Ambient Water Quality Criteria established under Sections 303 and 304(a) of the Clean Water Act (33 U.S.C. 1251-1376; 40 CFR 100–149, 40 CFR 131) http://www.epa.gov/ost/criteria/wqctable/	Washington Water Pollution Control Act - State Water Quality Standards for Surface Water (RCW 90.48; WAC 173-201A)	A, L	State surface water quality standards apply where the State has adopted, and EPA has approved, Water Quality Standards. Federal recommended Water Quality Criteria established under Section 304(a) of the Clean Water Act that are more stringent than State criteria and that are relevant and appropriate also apply. Both chronic and acute standards, and marine and freshwater are used as appropriate. Expected improvements to surface water quality will be achieved through remediation of site sediments; no active remediation of surface water will be conducted. Remedial action plans will define measures to be taken to comply with applicable surface water standards during remedial action implementation. CWA Section 304 includes federal criteria that are advisory only for CWA purposes, but nevertheless represent a cleanup standard/ARAR per Section 121(d)(2)(A)(ii) of CERCLA.
State Hazardous Waste Cleanup Rules	Washington State requirements for establishing numeric or risk-based standards and selecting cleanup actions	NA	Washington State Model Toxics Control Act (RCW 70.105D; WAC 173-340)	C, A, L	The portions of MTCA that deal with selection of cleanup levels, risk assessment, and remedy selection represent an ARAR for the Lockheed West Site in cases where they are more stringent than CERCLA and other federal and state environmental laws and rules. MTCA represents the regulatory authority for promulgation of the SMS. A waiver has been requested by Lockheed Martin for MTCA rule regarding selection of natural background concentrations as cleanup levels in cases where calculated risk-based threshold concentrations are below background concentrations.
Fish Tissue Quality	Concentrations of chemicals in fish tissues	Food and Drug Administration Maximum Concentrations of Contaminants in Fish Tissue (49 CFR 10372-10442)	NA	C	The Washington State Department of Health assesses the need for fish consumption advisories.
Waste Treatment, Storage, and Disposal	Hazardous Waste Management	Resource Conservation and Recovery Act (42 U.S.C. 7401-7642, 40 CFR 264, 265)	Washington State Dangerous Waste Regulations (RCW70.105; WAC 173-303)	C, A	Portions of RCRA and Washington State Dangerous Waste Regulations related to hazardous waste determination and analytical testing; onsite storage, treatment, and disposal are applicable to this project. State criteria for dangerous waste are broader than federal criteria. Based on the RI data, levels of sediment contamination do not appear to represent hazardous waste.
Land Disposal of Waste	Management and disposal of materials containing PCBs	Toxic Substance Control Act (15 U.S.C. 2605; 40 CFR761	Washington State Dangerous Waste Regulations (RCW70.105; WAC 173-303, -140, -141)	C, A	None
	Hazardous waste	Resource Conservation and Recovery Act Land Disposal Restrictions (42 U.S.C. 7401-7642; 40 CFR 268)			None
Solid Waste Disposal	Requirements for solid waste handling management and disposal	Solid Waste Disposal Act (42 U.S.C. 215103259-6901-6991; 40 CFR 257, -258)	Solid Waste Handling Standards (RCW 70.95; WAC 173-350)	C, A	Covers non-hazardous waste generated during remedial activities unless wastes meet recycling exemptions.
Dredge/Fill and Other In-water Construction Work	Discharge of dredged/fill material into navigable waters or wetlands	Clean Water Act (33 U.S.C. 401 et seq; 33 U.S.C. 141; 33 U.S.C. 1251-1316; 40 CFR 230, 231, 404; 33 CFR 320-330) Rivers and Harbor Appropriations Act (33 U.S.C. 401 et seq)	Hydraulic Code Rules (RCW 75.20; WAC 220-110)	C, A, L	Dredging and other in-water construction must meet specific standards that apply to any construction activity in or near state waters.
	Open-water disposal of dredged sediments	Marine Protection, Research and Sanctuaries Act (33 U.S.C. 1401-1445; 40 CFR 227)	Dredged Materials Management Program (RCW 79.90; WAC 332-30-166) USACE et al. (1988a,b; 1989)	C, A, L	Characterization and permitting process for unconfined open-water disposal of sediments.

Table 9-1.
Applicable or Relevant and Appropriate Requirements for the Lockheed West Site (Page 2 of 2)

Topic	Standard or Requirement	Regulatory Citation		ARAR Category C (Chemical-specific), A (Action-specific), and/or L (Location-specific)	Project-Specific Comments
		Federal	State or Local		
Discharge to Surface Water	Point source standards for new discharges to surface water	National Pollutant Discharge Elimination System (40 CFR 122, 125)	Discharge Permit Program (RCW 90.48; WAC 173-216, -222)	C, A, L	Remediation discharges must comply with substantive requirements of NPDES rules. If upland handling of sediment is planned, construction stormwater requirements will be addressed including development of a stormwater pollution prevention plan and implementation of best management practices. NPDES program requirements will be reviewed as part of project final design.
Pretreatment Standards	Permitting and pretreatment requirements for discharges to a POTW	National Pretreatment Standards (40 CFR 403);	40 CFR Part 403; Metro District Wastewater Discharge Ordinance (KCC) To be considered (as is local requirement)	C, A, L	Discharges to POTWs are considered off-site activities; pretreatment and permitting requirements would be applicable.
Noise	Maximum allowable noise levels during construction activities	NA	Noise Control Act of 1974 (RCW 80.107; WAC 173-60) Seattle Municipal Code (SMC Title 25.800)	A, L	Project will comply with state and local ordinance for noise levels.
Shoreline	Construction and development	Coastal Zone Management Act (16 U.S.C. 1451 et seq.)	Shoreline Management Act (WAC 173-16); King County and City of Seattle Shoreline Master Plans (KCC Title 25; SMC 23.60)	A, L	For construction within 200 feet of the shoreline.
Habitat for Fish, Plants, or Birds	Evaluate and mitigate habitat impacts	Clean Water Act (Section 404 (b)(1)) U.S. Fish and Wildlife Mitigation Policy (44 FR 7644) U.S. Fish and Wildlife Coordination Act (16 U.S.C. 661 et seq) Migratory Bird Treaty Act (16 U.S.C. 703-712)	Washington Department of Fisheries Habitat Management Policy (POL-410)	A, L	Habitat mitigation needs will be assessed and addressed in the remedial design. Mitigation requirements will be defined in project permitting and vary with the type of work conducted.
Critical (or Sensitive) Area	Regulates construction in environmentally critical or sensitive areas	NA	Growth Management Act (RCW 37.70a); King County Critical Area Ordinance (KCC Title 21A.24); City of Seattle (SMC 25.09)	A, L	The site is within an industrially zoned area and not within a critical or sensitive area.
Floodplain Protection	Avoid adverse impacts, minimize potential harm	Executive Order 11988, Protection of flood plains (40 CFR 6, Appendix A) ; FEMA National Flood Insurance Program Regulations (44 CFR 60.3Ld)(3).	Local ordinances: KCC Title 9 and SMC 25.09.	A, L	For in-water construction activities, including any dredge or fill operations.

Notes:
ARAR = Applicable or relevant and appropriate requirement
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CFR = Code of Federal Regulations
CWA = Clean Water Act
DMMP = Dredged Materials Management Program
FEMA = Federal Emergency Management Agency
KCC = King County Code
Lockheed Martin = Lockheed Martin Corporation
MCL = Maximum Contaminant Level
MCLG = Maximum Contaminant Level Goal
MTCA =Model Toxics Control Act
NPDES = National Pollutant Discharge Elimination System
NA = Not applicable
NEPA = National Environmental Policy Act
PCBs = Polychlorinated biphenyls
POTW = Publically Owned Treatment Works
PSDDA = Puget Sound Dredge Disposal Analysis
RCRA = Resource Conservation and Recovery Act
RCW =Revised Code of Washington
SEPA =State Environmental Policy Act
SMC = Seattle Municipal Code
TSCA = Toxic Substances Control Act
SMS = Washington Sediment Management Standards
U.S.C. = United States Code
WAC = Washington Administrative Code

Table 9-2.

Other Legal, Permitting, or Administrative Requirements for the Lockheed West Site

Topic	Standard or Requirement	Regulatory Citation		Preliminary Screening and Comments
		Federal	State	
Native American Graves, Sacred Sites, and Archaeological Resources	Work must cease if Native American Burial sites or cultural items are discovered Work must cease if sacred religious sites are discovered Regulates removal and disturbance of archeological resources	Native American Graves Protection and Repatriation Act (25 U.S.C. 3001 et seq.; 43 CFR Pt. 10) American Indian Religious Freedom Act (42 U.S.C. 1996 et seq.); Archaeological Resources Protection Act (16 U.S.C. 470 aa et seq.; 43 CFR Part 7)	NA	The occurrence of Native American graves and archaeological sites does not appear to represent a likely scenario for sediment dredging and capping alternatives being evaluated at the Lockheed West Site. While the Site is in the "usual and accustomed" fishing areas for two tribes, the remediation area has been historically dredged and filled. A Section 106 consultation with the Tribes will occur prior to remedial activities.
Critical Habitat for Endangered Species	Conserve endangered or threatened species, consult with species listing agencies	Endangered Species Act of 1973 (16 U.S.C. 1531 et seq; 50 CFR 200, -402); Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1801-1884)	Endangered, threatened, and sensitive wildlife species classification (WAC 232-12-297)	Consult, and obtain Biological Opinions. Based on the RI findings, critical habitat does not appear to be present at the Lockheed West Site. However, EPA will consult with and obtain Biological Opinions from appropriate agencies. Chinook salmon are listed as threatened species and federal agencies must confer with NOAA Fisheries on any action that may impact listed species.
Historic Sites or Structures	Requirement to avoid, minimize, or mitigate impacts to historic sites or structures	National Historic Preservation Act (16 U.S.C. 470f; 36 CFR Parts 60, 63 and 800)		Considered if implementation of the selected remedy involves removal of historic sites or structures. The only structures in the remediation area are old pilings and piping that do not appear to be of historic significance.
Occupational Health and Safety	Requirements to provide for worker health and safety	Occupational Safety and Health Act (29 U.S.C.; 29 CFR)	Washington Industrial Safety and Health Act (RCW 49.17; WAC 296)	This project has been performed and will continue to be performed in compliance with OSHA and WISHA requirements. Project final design will include definition of contractor safety requirements, including preparation and compliance with a project Health and Safety Plan, worker training and record-keeping requirements, and other applicable measures.
State-Owned Aquatic lands	Requirements that DNR must follow in issuing land-use authorizations for remedial actions	NA	Washington Aquatic Lands Statutes (RCW 79.100 to 79.145)	Portions of the Site are property owned and leased by the State of Washington. Remedial action that limits public use of state-owned aquatic land by requiring institutional controls, or other types of management control, requires a use authorization (easement) from the State.

Notes:
N/A = not applicable
CFR = Code of Federal Regulations
DNR = Washington Department of Natural Resources
EPA = U.S. Enviornmental Protection Agency
NOAA = National Oceanic and Atmospheric Administration
OSHA = Occupational Safety and Health Act
RCW = Revised Code of Washington
RI = Remedial Investigation
U.S.C. = United States Code
WAC = Washington Administrative Code
WISHA = Washington Industrial Safety and Health Act

Table 9-3. Potential Preliminary Remediation Goals Considered for Risk-Driver Contaminants in Lockheed West Site Surface Sediment

Contaminant of Concern	Practical Quantitation Limits		Background Concentrations in Sediment					Site Surface Sediment Data (95 UCL)		Risk-Based Threshold Concentrations/ARARs (Benthic Organisms)									
											Tribal RME Seafood Consumption				Direct Contact (netfishing, clamming, beach play)[6/]	Ecological			
	EPA Method	MDL/RL[1/]	Natural[2/]	Provisional Anthro-pogenic[3/]	Elliott Bay Deep Basin[4/]	Elliott Bay Urban/ Mid-Bay[4/]	Elliott Bay Harbor/ Inner Bay[4/]	Subtidal + Intertidal	Intertidal	Spatial Scale of Exposure[5/]	Adult 10^{-4} Cancer Risk	Adult 10^{-5} Cancer Risk	Adult 10^{-6} Cancer Risk	Child Non-Cancer HQ = 1	10^{-6} Cancer Risk	Benthic Organisms	Fish7/ (sitewide)	Crab7/ (sitewide)	Sandpiper[7/] (intertidal)
Total PCBs (µg/kg dw) Food-web model regression-based[8/]	8082	5.3/20 [9/]	2.0 (congener data)	35	48	119	355	498	41.8	Sitewide (seafood, netfishing, fish, crab)	**<1** [10/]	nc (bg)[10/]	nc (bg)[10/]	**<1** [10/]	Not COC	n/a	**100**	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	**<5**	nc (bg)	nc (bg)	**<5**	Not COC	n/a	n/a	n/a	Not COC
								240 mg/kg OC, max	77 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**12/65 (OC)[11/] 180/1000 (dw)**	n/a	n/a	n/a
Total PCBs (µg/kg dw) BSAF-based[8]	8082	5.3/20 [9/]	2.0 (congener data)	35	48	119	355	498	41.8	Sitewide (seafood, netfishing, fish, crab)	**11**	**1.1**	**0.11**	**4.5**	Not COC	n/a	**55**	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	**25**	**2.5**	**0.25**	**10**	Not COC	n/a	n/a	n/a	Not COC
								240 mg/kg OC, max	77 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**12/65 (OC)[11/] 180/1000 (dw)**	n/a	n/a	n/a
Arsenic (mg/kg dw)	6020	0.02/0.2	7	9	9.13	8.44	73.40	109	192	Sitewide (seafood, netfishing, fish, crab)	**10**	**1**	**0.05**	**100**	**5**	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	**0.4**	**0.003**	**0.000023**	**10**	**1.5**	n/a	n/a	n/a	Not COC
								204 max	330 max	Point	n/a	n/a	n/a	n/a	n/a	**57/93[11/]**	n/a	n/a	n/a
cPAH (µg TEQ/kg dw)	8270C	7.3/20	9	70	125	757	1,210	958	182	Sitewide (seafood, netfishing, fish, crab)	**22**	**2.2**	**0.22**	n/a	**550**	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	**30**	**3**	**0.3**	n/a	**150**	n/a	n/a	n/a	Not COC
										Point	n/a	n/a	n/a	n/a	n/a	Not COC	n/a	n/a	n/a
Lead (mg/kg dw)	6020	0.12/2	11	NA	26.9	47	66.9	146 (mean)[12/]	660	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	**10**	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	**10**	n/a	n/a	n/a	n/a	**50**
										Point	n/a	n/a	n/a	n/a	n/a	Not COC	n/a	n/a	n/a
Tributyltin (µg/kg dw)	Krone 1989	2.8/6	NA	NA	NA	NA	NA	2,810	36.4	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	**430**	n/a	n/a	**150**	**1,000**	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	**2,000**	n/a	n/a	n/a	n/a	Not COC
										Point	n/a	n/a	n/a	n/a	n/a	Not COC	n/a	n/a	n/a

Table 9-3. Potential Preliminary Remediation Goals Considered for Risk-Driver Contaminants in Lockheed West Site Surface Sediment

Contaminant of Concern	Practical Quantitation Limits		Background Concentrations in Sediment					Site Surface Sediment Data (95 UCL)		Risk-Based Threshold Concentrations/ARARs (Benthic Organisms)									
											Tribal RME Seafood Consumption				Direct Contact (netfishing, clamming, beach play)[6/]	Ecological			
	EPA Method	MDL/RL[1/]	Natural[2/]	Provisional Anthro-pogenic[3/]	Elliott Bay Deep Basin[4/]	Elliott Bay Urban/ Mid-Bay[4/]	Elliott Bay Harbor/ Inner Bay[4/]	Subtidal + Intertidal	Intertidal	Spatial Scale of Exposure[5/]	Adult 10^{-4} Cancer Risk	Adult 10^{-5} Cancer Risk	Adult 10^{-6} Cancer Risk	Child Non-Cancer HQ = 1	10^{-6} Cancer Risk	Benthic Organisms	Fish7/ (sitewide)	Crab7/ (sitewide)	Sandpiper[7/] (intertidal)
Copper (mg/kg dw)	6010B	0.04/0.2	24.9	NA	41.1	48.9	112	618	840	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	**400**	n/a	n/a	**114**	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	**400**	n/a	n/a	n/a	n/a	**420**
								1,900 max	1,310 max	Point	n/a	n/a	n/a	n/a	n/a	**390/390[11/]**	n/a	n/a	n/a
Mercury (mg/kg dw)	7471A	0.003/0.05	0.101	NA	0.175	0.438	0.335	0.61	0.26	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	**0.41**	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	**0.17**	n/a	n/a	n/a	n/a	Not COC
								2.94 max	0.42 max	Point	n/a	n/a	n/a	n/a	n/a	**0.41/0.59[11/]**	n/a	n/a	n/a
Dioxins/Furans (ng TEQ/kg dw)	--	--	2	3.6	--	--	--	No data	No data	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
										Point	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes:

= Risk drivers as a subset of COCs; for human health based on percentage of risk, for benthic invertebrates based on exceedance of CSL in at least 5% of locations, or for ecological receptors based on LOAEL HQ >1; and assumed for dioxins/furans.

Sediment risk-based threshold concentrations (RBTCs) for human seafood consumption and exposures of fish, crab, and sandpiper are estimated by modeling from acceptable risk-based tissue concentrations to corresponding sediment concentrations, using the same BSAFs and regression equations used in the risk calculations. Thresholds are based on rounded values.

1/ Reporting limits from Table 2-3, Appendix D (Surface Sediment QAPP) (Tetra Tech, 2008a, June Rev 3) in dry weight.

2/ Natural background values are 95 UCL on the mean data compiled in the "Bold Study".

3/ Provisional values originally determined by EPA (2007b) from data on upstream Green River surface sediment and suspended solids, and turning basin surface sediment and core data, as reported in Section 4 of the draft FS for the LDW (AECOM, 2009), and as revised in Table 3b of LDWG (2010).

4/ Elliott Bay "Deep Basin", "Urban", and "Harbor" values are 95 UCLs on the mean data reported for each dataset in EPA (2009a).

5/ The spatial scale of sitewide exposure is for seafood consumption, netfishing, and risks to fish; and intertidal-wide for clam ingestion, clam collection, and sandpiper exposures. Point exposure is for benthic invertebrates.

6/ Only carcinogenic risks shown, since no COCs other than arsenic were identified as risk drivers for non-cancer risks for direct contact pathways.

7/ COCs identified for fish, crab, and sandpiper based on LOAEL HQ > 1; RBTC threshold is LOAEL HQ = 1, with rounding.

8/ RBTCs for PCBs are based on (1) the regression equation from the LDW food-web model, and (2) alternative single value BSAFs presented to EPA Nov 13, 2008.

9/ PCB Reporting Limts taken from the "Bold Study" of background values in Puget Sound (EPA, 2009a). Range of RLs for undetected values are for undetected calculated total PCBs, not undetected values of individual Aroclors. Individual undetected Aroclors were not reported because they are not included in the calculation of total PCBs when other Aroclors are detected in the sample.

10/ Threshold was not calculatable, background assumed as basis of cleanup level. The lowest achievable cancer risk for tribal adult seafood at the listed RBTC is 2E-04, and non-cancer HQ for tribal child seafood is 5. (Note that the minimum achievable sediment threshold exceeds the risk criteria because of the use of the LDW food web model regression equations for the BSAF; the water component of the food web model drives the tissue concentrations at low sediment concentrations, such that below the identified sediment concentration no further reduction in risk is possible).

11/ Organic chemical criteria are SQS/CSL normalized to organic carbon and the dry weight equivalents are calculated based on an average sediment TOC content of 1.5%. Metals concentration units are mg/kg dw and the two values are SQS/CSL.

12/ Mean concentration, used for modeling lead risks to children.

bg = background
BSAF = biota-sediment accumulation factor
COC = contaminant of concern
cPAH = carcinogenic polycyclic aromatic hydrocarbon
CSL = cleanup screening level
dw = dry weight
LDW = Lower Duwamish Waterway
LOAEL = low observed adverse effect level
HQ = hazard quotient

µg/kg = micrograms per kilogram
mg/kg = milligrams per kilogram
MDL = method detection limit
ng TEQ/kg = nanograms toxicity equivalents per kilogram
NA = Not available in EPA or LDW documents, or not calculated
n/a = not applicable, either not relevant toxicity endpoint or not relevant pathway of exposure
nc (bg) = not calculated, RBTC value expected to be below background
PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl
QAPP = quality assurance project plan

RBTC = risk-based threshold concentration
RL = reporting limit
RME = reasonable maximum exposure
SMS = Sediment Management Standards
SQS = sediment quality standard
TBD = to be determined
TOC = total organic carbon
UCL = upper confidence limit

Table 9-4. Potential Preliminary Remediation Goals Considered for Non-Risk Driver Contaminants of Concern in Lockheed West Site Surface Sediment

Contaminant of Concern	Practical Quantitation Limits		Background Concentrations in Sediment					Site Surface Sediment Data (95 UCL or maximum)		Risk-Based Threshold Concentrations/ARARs (Benthic Organisms)									
											Tribal RME Seafood Consumption				Direct Contact (netfishing, clamming, beach play)[6/]	Ecological			
	EPA Method	MDL/RL[1/]	Natural[2/]	Provisional Anthro-pogenic[3/]	Elliott Bay Deep Basin[4/]	Elliott Bay Urban/ Mid-Bay[4/]	Elliott Bay Harbor/ Inner Bay[4/]	Subtidal + Intertidal	Intertidal	Spatial Scale of Exposure[5/]	Adult 10^{-4} Cancer Risk	Adult 10^{-5} Cancer Risk	Adult 10^{-6} Cancer Risk	Child Non-Cancer HQ = 1	10^{-6} Cancer Risk	Benthic Organisms[7/]	Fish8/ (sitewide)	Crab8/ (sitewide)	Sandpiper[8/] (intertidal)
Antimony (mg/kg dw)	6020	0.11/1	ND	NA	NA	NA	NA	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								194 max	126 max	Point	n/a	n/a	n/a	n/a	n/a	**150/200[9/]**	n/a	n/a	n/a
Cadmium (mg/kg dw)	6020	0.02/0.2	0.398	NA	0.29	0.295	0.434	0.36	0.45	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	**0.33**	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	**0.36**	n/a	n/a	n/a	n/a	Not COC
										Point	n/a	n/a	n/a	n/a	n/a	Not COC	n/a	n/a	n/a
Chromium (mg/kg dw)	6010B	0.09/0.5	35.6	NA	42.2	33.3	34	90	197.8	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	**90**	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	**85**	n/a	n/a	n/a	n/a	Not COC
								504 max	289 max	Point	n/a	n/a	n/a	n/a	n/a	**260/270[9/]**	n/a	n/a	n/a
Cobalt (mg/kg dw)	6020	0.03/0.3	9.6	NA	NA	NA	NA	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								23 max	38.6 max	Point	n/a	n/a	n/a	n/a	n/a	**10[9/]**	n/a	n/a	n/a
Nickel (mg/kg dw)	6020	0.38/1.0	36.6	NA	36.2	28.9	30	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								84.9 max	151 max	Point	n/a	n/a	n/a	n/a	n/a	**140/370[9/]**	n/a	n/a	n/a
Selenium (mg/kg dw)	6020	0.3/5.0	0.575	NA	0.99	0.621	0.524	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								1.2 max	0.7 max	Point	n/a	n/a	n/a	n/a	n/a	**1[9/]**	n/a	n/a	n/a
Vanadium (mg/kg dw)	6010B	0.03/0.3	43.3	NA	NA	NA	NA	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								95.6 max	68.6 max	Point	n/a	n/a	n/a	n/a	n/a	**57[9/]**	n/a	n/a	n/a

Table 9-4. Potential Preliminary Remediation Goals Considered for Non-Risk Driver Contaminants of Concern in Lockheed West Site Surface Sediment

Contaminant of Concern	Practical Quantitation Limits		Background Concentrations in Sediment					Site Surface Sediment Data (95 UCL or maximum)		Risk-Based Threshold Concentrations/ARARs (Benthic Organisms)									
											Tribal RME Seafood Consumption				Direct Contact (netfishing, clamming, beach play)[6]	Ecological			
	EPA Method	MDL/RL[1]	Natural[2]	Provisional Anthro-pogenic[3]	Elliott Bay Deep Basin[4]	Elliott Bay Urban/ Mid-Bay[4]	Elliott Bay Harbor/ Inner Bay[4]	Subtidal + Intertidal	Intertidal	Spatial Scale of Exposure[5]	Adult 10^{-4} Cancer Risk	Adult 10^{-5} Cancer Risk	Adult 10^{-6} Cancer Risk	Child Non-Cancer HQ = 1	10^{-6} Cancer Risk	Benthic Organisms[7]	Fish8/ (sitewide)	Crab8/ (sitewide)	Sandpiper[8] (intertidal)
Zinc (mg/kg dw)	6010B	0.29/0.6	59.7	NA	90.6	87.1	202	473	1,002	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	**410**	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	**410**	n/a	n/a	n/a	n/a	Not COC
								1,430 max	1,360 max	Point	n/a	n/a	n/a	n/a	n/a	**410/960**	n/a	n/a	n/a
Pentachloro-phenol (µg/kg dw)	8270C	37/100	ND	NA	ND	ND	ND	124	n/d	Sitewide (seafood, netfishing, fish, crab)	**5800**	**580**	**58**	n/a	Not COC	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/d	n/d	n/d	n/a	Not COC	n/a	n/a	n/a	Not COC
								540 max	n/d	Point	n/a	n/a	n/a	n/a	n/a	**360/690 (dw)**	n/a	n/a	n/a
Total Chlordanes (µg/kg dw)	8081A	0.964/1.0	ND	NA	ND	ND	0.833	7.5	1.1	Sitewide (seafood, netfishing, fish, crab)	**12**	**1.2**	**0.12**	n/a	Not COC	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	**110**	**11**	**1.1**	n/a	Not COC	n/a	n/a	n/a	Not COC
										Point	n/a	n/a	n/a	n/a	n/a	Not COC	n/a	n/a	n/a
Total DDTs (µg/kg dw)	8081A	1.1/2.0	ND	NA	1.57	355	14.3	75.5	3.1	Sitewide (seafood, netfishing, fish, crab)	**25**	**2.5**	**0.25**	**20**	Not COC	n/a	Not COC	**14**	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	**62**	**6.2**	**0.62**	**49**	Not COC	n/a	n/a	n/a	Not COC
										Point	n/a	n/a	n/a	n/a	n/a	Not COC	n/a	n/a	n/a
bis(2-Ethylhexyl) phthalate (µg/kg dw)	8270C	10.8/20	195	NA	ND	508	1060	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								59.8 mg/Kg OC, max	670 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**47/78 (OC) 710/1200 (dw)**	n/a	n/a	n/a
Acenaphthene (µg/kg dw)	8270C	9.36/20	6 (max)	NA	12	87.2	111	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								55 mg/Kg OC, max	280 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**16/57 (OC) 240/860 (dw)**	n/a	n/a	n/a

Table 9-4. Potential Preliminary Remediation Goals Considered for Non-Risk Driver Contaminants of Concern in Lockheed West Site Surface Sediment

Contaminant of Concern	Practical Quantitation Limits		Background Concentrations in Sediment					Site Surface Sediment Data (95 UCL or maximum)		Risk-Based Threshold Concentrations/ARARs (Benthic Organisms)									
											Tribal RME Seafood Consumption				Direct Contact (netfishing, clamming, beach play)[6/]	Ecological			
	EPA Method	MDL/RL[1/]	Natural[2/]	Provisional Anthro-pogenic[3/]	Elliott Bay Deep Basin[4/]	Elliott Bay Urban/ Mid-Bay[4/]	Elliott Bay Harbor/ Inner Bay[4/]	Subtidal + Intertidal	Intertidal	Spatial Scale of Exposure[5/]	Adult 10^{-4} Cancer Risk	Adult 10^{-5} Cancer Risk	Adult 10^{-6} Cancer Risk	Child Non-Cancer HQ = 1	10^{-6} Cancer Risk	Benthic Organisms[7/]	Fish8/ (sitewide)	Crab8/ (sitewide)	Sandpiper[8/] (intertidal)
Benzo(a)-anthracene (µg/kg dw)	8270C	8.34/20	4.3	NA	58	348	624	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								370 mg/Kg OC, max	170 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**110/270 (OC) 1700/4100 (dw)**	n/a	n/a	n/a
Benzo(a)-pyrene (µg/kg dw)	8270C	7.31/20	6.4	NA	87	632	856	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								470 mg/Kg OC, max	260 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**99/210 (OC) 1500/3200 (dw)**	n/a	n/a	n/a
Benzo(g,h,i)-perylene (µg/kg dw)	8270C	8.04/20	3.3	NA	76	359	463	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								310 mg/Kg OC, max	110 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**31/78 (OC) 470/1200 (dw)**	n/a	n/a	n/a
Total Benzo-fluoranthenes (µg/kg dw)	8270C	10.4/20	15.5	NA	153	891	2030	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								3,400 µg/kg dw, max	340 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**1800/3200 (dw)**	n/a	n/a	n/a
Chrysene (µg/kg dw)	8270C	8.09/20	4.5	NA	100	575	1730	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								540 mg/Kg OC, max	200 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**110/460 (OC) 1700/6900 (dw)**	n/a	n/a	n/a
Dibenzo(a,h)-anthracene (µg/kg dw)	8270C	8.35/20	2.7	NA	18	49	108	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								82 mg/Kg OC, max	28 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**12/33 (OC) 180/500 (dw)**	n/a	n/a	n/a

Table 9-4. Potential Preliminary Remediation Goals Considered for Non-Risk Driver Contaminants of Concern in Lockheed West Site Surface Sediment

Contaminant of Concern	Practical Quantitation Limits		Background Concentrations in Sediment					Site Surface Sediment Data (95 UCL or maximum)		Risk-Based Threshold Concentrations/ARARs (Benthic Organisms)									
											Tribal RME Seafood Consumption				Direct Contact (netfishing, clamming, beach play)[6/]	Ecological			
	EPA Method	MDL/RL[1/]	Natural[2/]	Provisional Anthro-pogenic[3/]	Elliott Bay Deep Basin[4/]	Elliott Bay Urban/ Mid-Bay[4/]	Elliott Bay Harbor/ Inner Bay[4/]	Subtidal + Intertidal	Intertidal	Spatial Scale of Exposure[5/]	Adult 10^{-4} Cancer Risk	Adult 10^{-5} Cancer Risk	Adult 10^{-6} Cancer Risk	Child Non-Cancer HQ = 1	10^{-6} Cancer Risk	Benthic Organisms[7/]	Fish8/ (sitewide)	Crab8/ (sitewide)	Sandpiper[8/] (intertidal)
Fluoranthene (µg/kg dw)	8270C	8.49/20	8	NA	165	753	29800	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								1,021 mg/Kg OC, max	610 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**160/1200 (OC) 2400/18000 (dw)**	n/a	n/a	n/a
Indeno(1,2,3-cd)-pyrene (µg/kg dw)	8270C	8.54/20	4.1	NA	94	491	391	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								310 mg/Kg OC, max	140 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**34/88 (OC) 510/1300 (dw)**	n/a	n/a	n/a
Phenanthrene (µg/kg dw)	8270C	8.63/20	4.8	NA	118	611	1110	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								410 mg/Kg OC, max	240 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**100/480 (OC) 1500/7200 (dw)**	n/a	n/a	n/a
Total HPAH (µg/kg dw)	8270C	10.4/20	61.3	NA	880	4830	62100	n/a	n/a	Sitewide (seafood, netfishing, fish, crab)	n/a	n/a	n/a	Not COC	n/a	n/a	Not COC	Not COC	n/a
										Intertidal (clam ingestion, clamming, beach play; sandpiper)	n/a	n/a	n/a	Not COC	n/a	n/a	n/a	n/a	Not COC
								4,712 mg/Kg OC, max	2,008 µg/kg dw, max	Point	n/a	n/a	n/a	n/a	n/a	**960/5300 (OC) 14000/80000 (dw)**	n/a	n/a	n/a

Notes:

Risk drivers are defined as a subset of COCs; for human health based on percentage of risk, for benthic invertebrates based on exceedance of CSL in at least 5% of locations, or for ecological receptors based on LOAEL HQ >1; and assumed for dioxins/furans.

Sediment risk-based threshold concentrations (RBTCs) for human seafood consumption and exposures of fish, crab, and sandpiper are estimated by modeling from acceptable risk-based tissue concentrations to corresponding sediment concentrations, using the same BSAFs and regression equations used in the risk calculations. Thresholds are based on rounded values.

1/ Reporting limits from Table 2-3, Appendix D (Surface Sediment QAPP) (Tetra Tech, 2008a, June Rev 3) in dry weight; except for antimony, RL is from the "Bold Study".

2/ Natural background values are 95 UCL on the mean of the data compiled in the "Bold Study", except cobalt and vanadium are mean values from reference areas reported in Section 4 of the draft FS report for LDW (AECOM, 2009).

3/ Provisional values originally determined by EPA (2007b) from data on upstream Green River surface sediment and suspended solids, and turning basin surface sediment and core data, as reported in Section 4 of the draft FS for the LDW site (AECOM 2009), and as revised in Table 3b of LDWG (2010).

4/ Elliott Bay "Deep Basin", "Urban", and "Harbor" values are 95 UCLs on the mean data reported for each data set in EPA (2009a).

5/ The spatial scale of sitewide exposure is for seafood consumption, netfishing, and risks to fish; and intertidal-wide for clam ingestion, clam collection, and sandpiper exposures. Point exposure is for benthic invertebrates.

6/ Only carcinogenic risks shown, since no COCs other than arsenic were identified as risk drivers for non-cancer risks for direct contact pathways.

7/ Unless otherwise indicated, organic chemical criteria are SQS/CSL normalized to organic carbon, or calculated to dw based on an average sediment TOC content of 1.5%; metals concentration units are mg/kg dw and the two values are SQS/CSL.

8/ COCs identified for fish, crab, and sandpiper based on LOAEL HQ > 1; RBTC threshold is LOAEL HQ = 1, with rounding.

9/ Criteria are LAET and 2LAET or SL and ML (Gries and Waldow, 1996; NOAA, 2008; USACE, 2000).

BSAF = biota-sediment accumulation factor
COC = contaminant of concern
CSL = cleanup screening level
dw = dry weight
HPAH = high molecular weight polycyclic aromatic hydrocarbon
LDW = Lower Duwamish Waterway
LOAEL = low observed adverse effect level
µg/kg = micrograms per kilogram
mg/kg = milligrams per kilogram
NA = Not available in EPA or LDW documents, or not calculated
n/a = not applicable, either not relevant toxicity endpoint or not relevant pathway of exposure
n/d = not detected
PCB = polychlorinated biphenyl
QAPP = quality assurance project plan
RBTC = risk-based threshold concentration
RL = reporting limit
SMS = Sediment Management Standards
SQS = sediment quality standard
TOC = total organic carbon

Table 9-5. Summary of Preliminary Remediation Goals for Risk-Driver Contaminants of Concern in Lockheed West Site Surface Sediment

Risk-Driver Contaminant of Concern	Spatial Scale of Exposure[1/]	RAO 1: Human Seafood Consumption[2/]	RAO 2: Human Direct Contact[2/]	RAO 3: Benthic Organisms[3/]	RAO 4: Ecological (Fish, Crab, Sandpiper)[4/]
Total PCBs (µg/kg dw)	Sitewide	2	n/a	n/a	100
	Intertidal	2	n/a	n/a	n/a
	Point	n/a	n/a	12 (OC)/180 (dw)	n/a
cPAHs (µg TEQ/kg dw)	Sitewide	9	550[6/]	n/a	n/a
	Intertidal	9	150[7/]	n/a	n/a
	Point	n/a	n/a	n/a[8/]	n/a
Arsenic (mg/kg dw)	Sitewide	7	7	n/a	n/a
	Intertidal	7	7	n/a	n/a
	Point	n/a	n/a	57	n/a
Lead (mg/kg dw)	Sitewide	11	n/a	n/a	n/a
	Intertidal	11[9/]	n/a	n/a	50
	Point	n/a	n/a	n/a	n/a
Tributyltin (µg/kg dw)	Sitewide	430	n/a	n/a	150
	Intertidal	2,000[9/]	n/a	n/a	n/a
	Point	n/a	n/a	n/a	n/a
Copper (mg/kg dw)	Sitewide	400	n/a	n/a	114
	Intertidal	400[9/]	n/a	n/a	420
	Point	n/a	n/a	390	n/a
Mercury (mg/kg dw)	Sitewide	0.41	n/a	n/a	n/a
	Intertidal	0.17	n/a	n/a	n/a
	Point	n/a	n/a	0.41	n/a
Dioxins/Furans (ng TEQ/kg dw)	Sitewide	2	37[10/]	n/a	n/a
	Intertidal	2	13[10/]	n/a	n/a
	Point	n/a	n/a	n/a	n/a

1/ The spatial scale of exposure is measured as sitewide (i.e., all subtidal and intertidal sediments), intertidal sediments only, and point measurements at single locations throughout the site (i.e., all subtidal and intertidal sediment locations) or at single locations in intertidal sediment only. The spatial scale is RAO-specific, with sitewide exposures applicable to human seafood consumption, human direct contact, and exposures of fish and crab. Intertidal-only exposures are applicable to human consumption of clams from intertidal areas and exposures of sandpiper. Point exposures are applicable to benthic organisms, which are evaluated at single station locations. The statistical metric for sitewide and intertidal evaluation of alternatives and compliance monitoring is the upper confidence limit on the mean, whereas point exposures are evaluated with concentration data at single locations.

2/ PRGs are based on 10-6 cancer risk for carcinogens (e.g., PCBs, cPAHs, arsenic) or on a child exposure hazard quotient of 1 for non-carcinogens (lead, tributyltin, copper). Where PRGs based on carcinogenic risks are below background, the background concentration is selected.

3/ Applicable on a point exposure only. Values shown for PCBs are the organic carbon-normalized SQS and the dry weight equivalent based on an average sediment TOC content of 1.5%; for all other compounds values are dry weight. Under the SMS, sediment cleanup standards are established on a site-specific basis within an allowable range. The SQS and CSL define this range. For chemicals without SMS, LAET and 2LAE values or the SL and ML of the DMMP define this range. For this FS, the PRG has been set at the lowest end of the ranges. However, the final cleanup standard will be set in consideration of the net environmental effects, cost, and technical feasibility of different cleanup alternatives.

4/ PRGs for sitewide exposure are the lowest for either fish or crab; PRGs for intertidal exposure are for sandpiper.

6/ The PRG for sitewide direct contact is based on netfishing.

7/ The PRG for intertidal direct contact is based on the lowest for either tribal clamming or child beach play exposures.

8/ Low- and high-molecular weight PAHs are addressed by SMS criteria, set for groups of PAHs and for individual compounds.

9/ The PRG for intertidal seafood consumption is based on consumption of clams from the intertidal sediment.

10/ PRGs based on values presented in the Draft Final FS for the Lower Duwamish Waterway (AECOM, 2010) site-wide and tribal clamming (intertidal)

n/a = compounds do not present a risk for the RAO scenario.
mg/kg dw = milligrams per kilogram dry weight
µg/kg dw = micrograms per kilogram dry weight
ng TEQ/kg dw = nanograms toxicity equivalents per kilogram dry weight
µg TEQ/kg dw = micrograms Toxicity Equivalents per kilogram dry weight
OC = Organic Carbon

Table 9-6. Summary of Preliminary Remediation Goals for Non-Risk Driver Contaminants of Concern in Lockheed West Site Surface Sediment

Risk Driver Contaminant of Concern	Spatial Scale of Exposure[1/]	RAO 1: Human Seafood Consumption[2/]	RAO 2: Human Direct Contact[2/]	RAO 3: Benthic Organisms[3/]	RAO 4: Ecological (Fish, Crab, Sandpiper)[4/]
Antimony (mg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	150	n/a
Cadmium (mg/kg dw)	Sitewide	0.398	n/a	n/a	n/a
	Intertidal	0.398	n/a	n/a	n/a
	Point	n/a	n/a	n/a	n/a
Chromium (mg/kg dw)	Sitewide	90	n/a	n/a	n/a
	Intertidal	85	n/a	n/a	n/a
	Point	n/a	n/a	260	n/a
Cobalt (mg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point	n/a	n/a	10	n/a
Nickel (mg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point	n/a	n/a	140	n/a
Selenium (mg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	1	n/a
Vanadium (mg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point	n/a	n/a	57	n/a
Zinc (mg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point	n/a	n/a	410	n/a
Pentachlorophenol (µg/kg dw)	Sitewide	58	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	360	n/a
Total Chlordanes (µg/kg dw)	Sitewide	0.96[5/]	n/a	n/a	n/a
	Intertidal	1.1	n/a	n/a	n/a
	Point	n/a	n/a	n/a	n/a
Total DDTs (µg/kg dw)	Sitewide	1.1[5/]	n/a	n/a	14
	Intertidal	1.1[5/]	n/a	n/a	n/a
	Point	n/a	n/a	n/a	n/a
bis(2-ethylhexyl) phthalate (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	47 (OC)/710 (dw)	n/a
Acenaphthene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	16 (OC)/240 (dw)	n/a
Benzo(a)anthracene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	110 (OC)/1,700 (dw)	n/a
Benzo(a)pyrene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	99 (OC)/1,500 (dw)	n/a
Benzo(g,h,i)perylene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	31 (OC)/470 (dw)	n/a
Total Benzofluoranthenes (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	1,800	n/a

Table 9-6. Summary of Preliminary Remediation Goals for Non-Risk Driver Contaminants of Concern in Lockheed West Site Surface Sediment

Risk Driver Contaminant of Concern	Spatial Scale of Exposure[1/]	RAO 1: Human Seafood Consumption[2/]	RAO 2: Human Direct Contact[2/]	RAO 3: Benthic Organisms[3/]	RAO 4: Ecological (Fish, Crab, Sandpiper)[4/]
Chrysene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	110 (OC)/1,700 (dw)	n/a
Dibenzo(a,h)-anthracene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	12 (OC)/180 (dw)	n/a
Fluoranthene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	160 (OC)/2,400 (dw)	n/a
Indeno(1,2,3-cd)-pyrene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	34 (OC)/510 (dw)	n/a
Phenanthrene (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	100 (OC)/1,500 (dw)	n/a
Total HPAH (µg/kg dw)	Sitewide	n/a	n/a	n/a	n/a
	Intertidal	n/a	n/a	n/a	n/a
	Point - Subtidal only	n/a	n/a	960 (OC)/14,400 (dw)	n/a

1/ The spatial scale of exposure is measured as sitewide (i.e., all subtidal and intertidal sediments), intertidal sediments only, and point measurements at single locations throughout the site (i.e., all subtidal and intertidal sediment locations) or at single locations in intertidal sediment only. The spatial scale is RAO-specific, with sitewide exposures applicable to human seafood consumption, human direct contact, and exposures of fish and crab. Intertidal-only exposures are applicable to human consumption of clams from intertidal areas and exposures of sandpiper. Point exposures are applicable to benthic organisms, which are evaluated at single station locations. The statistical metric for sitewide and intertidal evaluation of alternatives and compliance monitoring is the upper confidence limit on the mean, whereas point exposures are evaluated with concentration data at single locations.

2/ PRGs are based on 10^{-6} cancer risk for carcinogens (e.g., pentachlorophenol) or on a child exposure hazard quotient of 1 for non-carcinogens (cadmium). Where PRGs are below background, the background concentration is selected; where no background values are available (chlordanes and DDT), the method detection limit (MDL) is selected.

3/ Applicable on a point exposure only. Values shown for metals are dry weight; value for pentachlorophenol is dry weight; values for PAHs are the organic carbon-normalized SQS (mg/kg OC) and the calculated dry weight equivalent based on an average total organic carbon content in the sediments of 1.5%, except for total benzofluoranthenes, which is only dry weight. Under the SMS, sediment cleanup standards are established on a site-specific basis within an allowable range. The SQS and CSL define this range. For chemicals without SMS, LAET and 2LAET values or the SL and ML of the DMMP define this range. For this FS, the PRG has been set at the lowest end of the ranges. However, the final cleanup standard will be set in consideration of the net environmental effects, cost, and technical feasibility of different cleanup alternatives.

4/ PRGs for sitewide exposure are the lowest for either fish or crab; PRGs for intertidal exposure are for sandpiper.

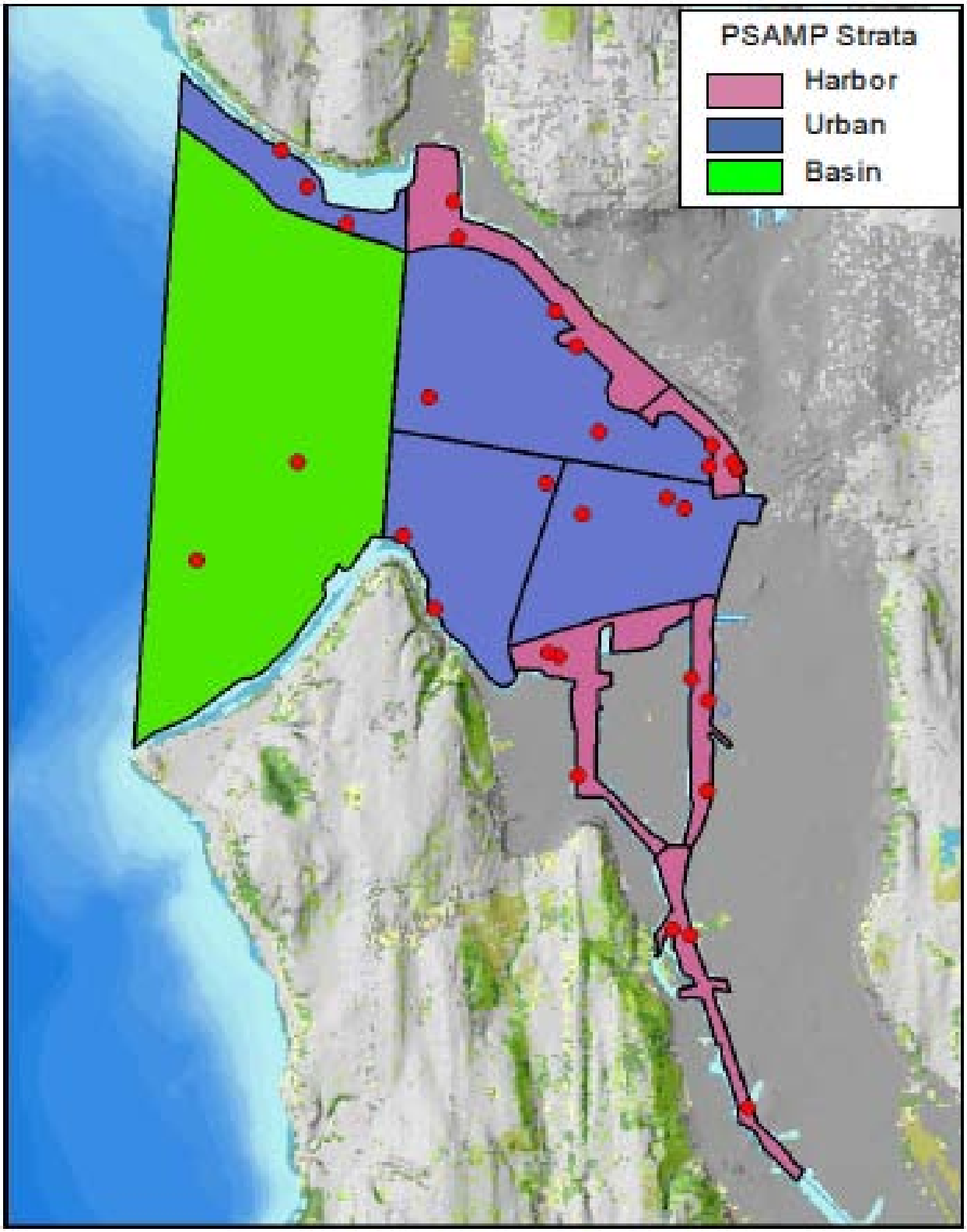
5/ The PRG is the MDL.

mg/kg dw = milligrams per kilogram dry weight

µg/kg dw = micrograms per kilogram dry weight

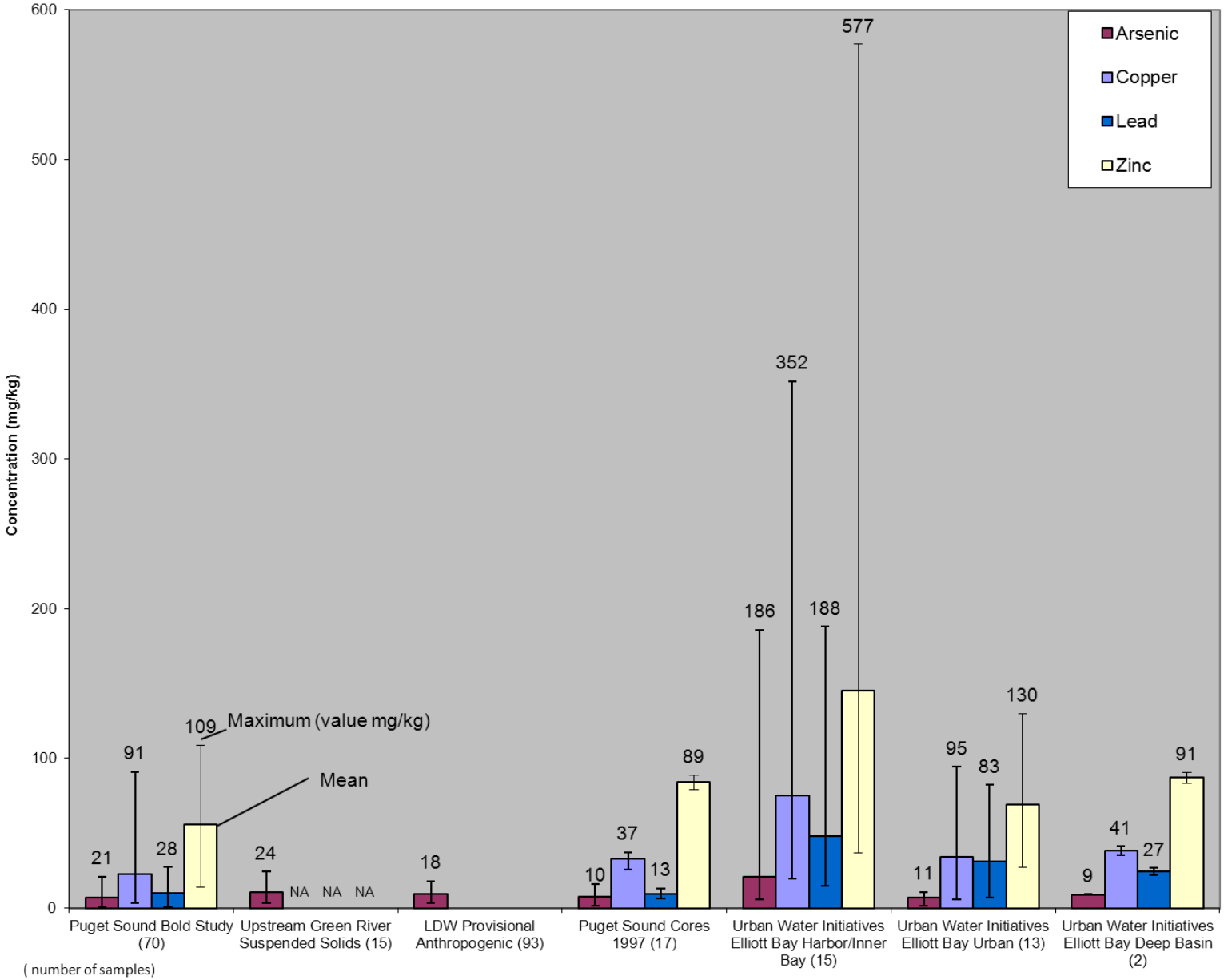
n/a = compounds do not present a risk for the RAO scenario.

OC = Organic Carbon



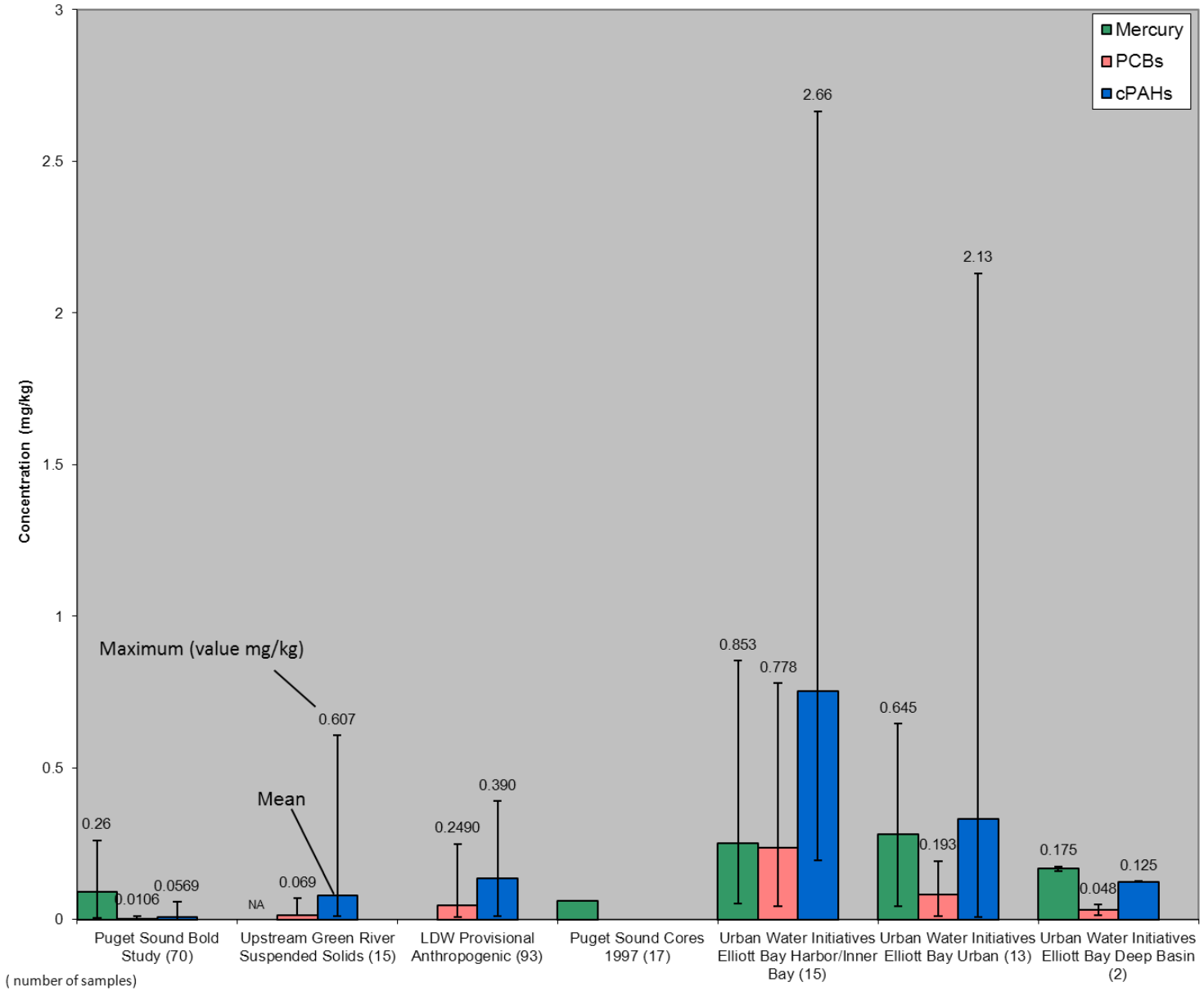
Source: Ecology 2009a

Figure 9-1. Station Locations for the 2007 Urban Waters Initiative Sediment Study



mg/kg = milligrams per kilogram

Figure 9-2. Comparison of Means and Ranges for Background Data Sets for Selected Metals



mg/kg = milligrams per kilogram

Figure 9-3. Comparison of Means and Ranges for Background Data Sets for Select Contaminants of Concern

SECTION 10
Screening of Remedial Technologies and Process Options

10.1 INTRODUCTION

The FS process for the Lockheed West Site is described in detail in the *RI/FS Work Plan* and consists of the following steps, the first of which is the subject of this section:

- Identify and screen appropriate remedial technologies and process options for cleanup of the Lockheed West Site sediments.
- Identify remedial action areas, remedial action levels, and assembly of remedial alternatives (Section 11).
- Evaluate assembled remedial alternatives against CERCLA criteria (Section 12).
- Recommend a best supported remedial alternative based on the comparative evaluation and relative ranking of the assembled alternatives (Section 13). The best supported alternative will be recommended to EPA for consideration in the preparation of the Preferred Plan for the Lockheed West Site.

The basis for identification of remedial technologies and process options is to satisfy the four RAOs developed for the Site and presented in Section 9.3. Representative, effective, and implementable process options are identified and selected to carry forward for developing remedial alternatives in Section 11. Detailed analysis of the remedial alternatives is performed in Section 12 of this FS.

10.1.1 Remedial Technologies and Process Options Screening Overview

The identification and screening of remedial technologies and process options used in this section follow EPA (1988) guidance and consist of the following three general steps:

- Identify and describe General Response Actions (GRAs), the broad categories of remedial actions that may be appropriate for the Lockheed West Site sediment (the medium of concern), as a single action or a combination of actions which may be taken to satisfy the RAOs developed for the Site.
- Identify and screen the technologies and process options (e.g., specific processes within each technology type) applicable to each GRA to ensure that only those technologies and process options applicable to the contaminants present, their physical matrix (e.g., sediments), and other site characteristics will be considered and carried forward into the assembly of alternatives. This screening will be based primarily on the effectiveness of the technology in addressing the contaminants at the Site but will also take into account the implementability and cost of each technology.
- Identify preliminary volumes or areas of sediment to which GRAs might be applied, taking into account the requirements for protectiveness as identified in the RAOs and the specific chemical and physical characteristics of the Lockheed West Site.

After the identification and screening steps are completed, the retained technologies and process options are assembled into sitewide alternatives in Section 11. The developed alternatives are defined according to size and configuration of the process options, time for remediation, rates of flow or treatment, spatial requirements, distances for disposal, and other factors necessary to evaluate the alternatives. Certain technologies and process options exhibiting potential applicability to the Site have been retained through the screening process but are not assembled into sitewide representative alternatives at this time. Reducing the number of process options does not preclude reexamination of these options during the remedial design; rather, it is a method to streamline the development and evaluation of the remedial alternatives for this FS. These technologies are retained for potential incorporation into alternatives during design, should further development of the current alternatives demonstrate a need to expand or replace currently assembled technologies.

10.1.2 Definitions

The terms General Response Action, technology types, and process options are used throughout this section and the definitions of these terms are provided below.

General Response Actions describe those actions that will satisfy the RAOs. GRAs describe in broad terms the kinds of media-specific remedial measures that could be applied to manage the human health and ecological risk drivers. They range from no action to complete removal with treatment or disposal, encompassing all the possible remedial actions that could be used to achieve the RAOs. Identifying GRAs appropriate to contaminated sediments reduces and focuses the list of technologies to be screened.

Technology Types are the general technologies that describe a means for achieving a GRA. Examples of technology types include dredging, dry excavation, and physical and chemical treatment. Removal is a GRA that can be achieved using excavation or dredging technologies whereas treatment is a GRA that can be achieved using physical, biological, or chemical technologies.

Process Options are specific processes within each technology type. For example, chemical treatment, which is a technology type, includes such process options as solvent extraction and slurry oxidation. Process options are selected based on the characteristics of the medium and the technologies available to address the medium.

The three categories (GRAs, technology types, and process options) defined above provide a structure for identifying and screening technologies and administrative tools available for implementing remedial actions.

10.1.3 Screening Criteria for Candidate Technologies

According to EPA (1988) guidance, the initial screening of potential remedial technologies (and associated process options) identified for each GRA is based on effectiveness, implementability, and cost. Technologies may be applicable to all or only portions of the Lockheed West Site due to Site-specific factors. Technologies considered should be commercially available and have been proven on a project or projects similar in size and site conditions to the Site.

Three screening criteria for candidate technologies are defined as follows:

1. **Effectiveness** is the degree to which RAOs can be attained for Lockheed West using a technology. This criterion is also used to evaluate the short-term and long-term adverse effects of the potential remedial alternative on the environment. Evaluation of effectiveness includes the following: 1) the potential effectiveness of technology/process options in processing the estimated volumes of sediment; 2) potential impacts to human health and the environment during the construction and implementation phase; and 3) the degree to which the technology/process is proven and reliable given the risk drivers and conditions of Lockheed West Site sediments.

2. **Implementability** addresses the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation. It addresses whether the intended remedial alternative can be implemented in a specific area requiring remediation. Factors to be considered in the evaluation of implementability include Site access (e.g., security screening and site use criteria for the Port of Seattle's Homeland Security personnel, security requirements for waters adjacent to Port facilities), Site bathymetric conditions, physical obstructions such as piers and berthed and moored vessels, water depths, depths of sediment contamination, and sediment transport and disposal considerations.

   Other factors to be considered when evaluating the implementability of a remediation technology include the following: meeting federal, state, and local regulations; the degree and speed of remediation; size and availability of equipment; local and regional agency project support; public acceptance; anticipated future land use; and other planned and/or ongoing projects and activities at or near the Lockheed West Site.

3. **Order-of-magnitude costs** are estimated based on experience with the technology on similar projects and include relative costs for equipment, labor, waste management, and permitting, among others that are required to design and construct the process options being evaluated. Order-of-magnitude costs by themselves are not used to screen out a potential restoration option but are used in consideration of, and in combination with, the other screening criteria.

10.1.3.1 Sustainability Considerations

In addition to the three CERCLA screening criteria described above, EPA recognizes that incorporation of sustainability principles can help increase the environmental, economic, and social benefits of cleanup (EPA, 2008b). EPA Region 10 has a *Clean and Green Policy* that applies to all Superfund cleanups to enhance the environmental benefits of federal cleanup

programs by promoting technologies and practices that are sustainable (EPA, 2009f, 2010b). The objectives of the *Clean and Green Policy* include the following: 1) protect human health and the environment by achieving remedial action goals; 2) support sustainable human and ecological use and reuse of remediated land; 3) minimize impacts to water quality and water resources; 4) reduce air toxics emissions and greenhouse gas production; 5) minimize material use and waste production; and 6) conserve natural resources and energy. The EPA Green Remediation strategy incorporates recognition that opportunities to decrease the environmental footprint of cleanup activities and maximize the environmental outcome of a cleanup exist throughout a project's life, extending from site investigation through development of cleanup alternatives and remedy design, construction, operation, and monitoring (EPA, 2010b). Green remediation comprises a range of best management practices that may be applied throughout the Superfund cleanup process. These practices provide potential means to improve waste management; conserve or preserve energy, fuel, water, and other natural resources; reduce greenhouse gas emissions; promote sustainable long-term stewardship; and reduce adverse impacts on local communities during and after remediation activities. Consistent with the EPA Green Remediation strategy, Lockheed Martin will explore and implement sustainability measures to reduce the environmental footprint of cleanup activities developed in this FS during remedial design and implementation. In this section, sustainability criteria were not formally used to screen potentially applicable technologies; however, they are considered during detailed evaluation of each alternative in Section 12 and CERCLA comparative evaluations of alternatives in Section 13. These sustainability measures were not discussed under detailed evaluation of short-term environmental impacts of each alternative; however, potential measures and best management practices that could be applied during cleanup activities are briefly discussed in Appendix G.

10.1.4 Guidance

Remedial technologies and remedial alternatives evaluated in the FS are based on the general range of Lockheed West Site sediment characteristics, physical conditions, and the nature, extent, and concentration of the major risk drivers (cPAHs, arsenic, copper, lead, mercury, TBT, PCBs, and dioxins/furans). Potential remedial technologies considered in the FS are also evaluated in accordance with requirements of CERCLA and the NCP. Documents that have

guided the identification and screening of applicable technologies and assembly of preliminary alternatives include the following:

- The Administrative Settlement Agreement and Order on Consent and Accompanying Statement of Work for the Lockheed West Site (EPA Docket No. CERCLA-10-2006-0321);
- Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (EPA, 1988);
- A Risk-Management Strategy for PCB-Contaminated Sediments (NRC, 2001);
- Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (EPA, 2005b);
- Land Use in the CERCLA Remedy Selection Process (EPA, 1995); and
- Principles for Managing Contaminated Sediment at Hazardous Waste Sites (EPA, 2002d).

10.1.5 Section Organization

The remainder of this section is organized as follows:

- Section 10.2 identifies and describes the GRAs for the Lockheed West Site on the basis of general conditions and risk drivers.
- Section 10.3 details the screening process for candidate technologies and the Site characteristics considered during the identification and screening process.
- Sections 10.4 through 10.10 present and evaluate the group of technologies and process options selected by screening for eight of the GRAs. Technologies and process options are initially screened against the criteria presented in Section 10.3 and the Site-specific factors such as operational constraints that will influence implementability or effectiveness are identified.
- Section 10.11 presents the results of the retained technologies after technology screening and briefly describes the primary factors that influenced the decision to retain or eliminate a particular technology.

10.2 IDENTIFICATION AND DESCRIPTIONS OF GENERAL RESPONSE ACTIONS

GRAs are medium-specific actions that can be used to satisfy RAOs. The remediation of contaminated sediments can be accomplished using a number of different technologies. The

GRAs appropriate for consideration in the remediation of contaminated sediments at the Lockheed West Site are as follows:

- No Action,
- Institutional Controls,
- Monitored Natural Recovery,
- Enhanced Natural Recovery,
- Containment,
- Removal,
- *In situ* treatment,
- *Ex situ* treatment,
- Disposal/Reuse, and
- Combined Actions.

Each of these is briefly described below and discussed in more detail in Sections 10.4 through 10.10.

10.2.1 No Action

No Action is a default retained technology, as required by CERCLA. No Action can only be selected where the site poses no unacceptable risks to human health or the environment. The Lockheed West Site risk assessments showed unacceptable risks to human health and the environment (Tetra Tech and Pascoe, 2009a,b); therefore, the No Action alternative is not discussed in detail in this FS.

10.2.2 Institutional Controls

Institutional controls are non-engineered controls such as legal or administrative measures that restrict human use or access of the site, thereby preventing or reducing exposure to contaminants by limiting or controlling activities that could lead to human exposure (EPA 2005b). Fish consumption advisories, restrictions on use of the waterway, deed restrictions, and restrictive covenants are examples of institutional controls. Institutional controls typically are used in conjunction with engineering measures such as containment, natural recovery, and *in s itu* treatment.

When developing institutional controls, consideration must be given to the nature and future use of the Site and surrounding areas. Access restrictions that conflict with Native American usual and accustomed harvest areas will also be avoided to the extent practicable.

10.2.3 Monitored Natural Recovery

Monitored natural recovery (MNR) of contaminated sediments relies on naturally occurring physical, chemical, and/or biological processes to isolate, destroy, or otherwise reduce the mobility or toxicity of contaminants. The acceptability of natural recovery as a response action is dependent upon the time to recover to acceptable contaminant levels and whether those recovery processes are permanent or reversible. Monitored natural recovery is based on a long-term monitoring program designed to observe and assess sediment chemistry and biological health. Results of the monitoring program determine the progress of natural recovery towards achieving RAOs and identify the need for future actions, in the event natural processes do not achieve goals as predicted.

10.2.4 Enhanced Natural Recovery

Enhanced natural recovery (ENR) typically involves the application of thin layers of clean material over areas where natural recovery processes are already occurring at a rate that is insufficient to reduce risks within an acceptable time frame. However, ENR is not being used to jumpstart the MNR processes at the Site, as the data necessary to fully evaluate MNR (e.g., sedimentation rate) were not collected during the RI. Instead, ENR is evaluated through contaminant concentration reduction through biological/physical mixing processes with an assumption of no new sediment deposition. By applying thin layers of clean sediments over an area and allowing natural re-sorting or bioturbation to mix the contaminated and clean sediment layers, the natural recovery process is accelerated and results in a surface layer with chemical concentrations within acceptable levels. A monitoring program and institutional controls would likely be conducted in conjunction with ENR (EPA, 2005b).

10.2.5 Containment (Capping)

Containment is in-place physical isolation or immobilization of contaminants in sediment through *in situ* capping. Although some sediment remediation guidance documents (Averett et

al., 1990; EPA, 1998) include contained aquatic disposal and confined disposal facilities (CDFs) in the containment category, these are discussed as disposal alternatives in this document.

With effective *in situ* cap placement, the bioavailability and mobility of contaminants present in the underlying sediments would be immediately limited because the biota are physically isolated from the contaminated sediments. A long-term monitoring program and institutional controls are required to verify and maintain the integrity and performance of the cap.

10.2.6 Removal

Removal refers to the dredging or excavation of contaminated sediments from a site. Following removal, the dredge material is transferred to a treatment or a disposal facility. Excavation is removal of sediments in the absence of overlying water, whereas dredging is removal of sediment through the water column.

10.2.7 *In Situ* Treatment

In s itu treatment is the in-place application of chemical or biological methods for reducing contaminant concentrations, mobility, or toxicity. The sediment is not removed from the site during or after treatment. Examples of *in situ* treatment include biodegradation, oxidation, sediment flushing, and ground freezing.

10.2.8 *Ex Situ* Treatment

Ex si tu treatment involves post-removal application of treatment technologies to transform, destroy*, or immobilize* COCs in the contaminated dredge material. *Ex situ* treatment is performed to meet chemical and physical requirements for treatment or disposal; and/or to reduce the volume/weight of sediment that requires transport, treatment, or restricted disposal. Examples of *ex si tu* treatment include stabilization, separation, solidification, thermal destruction, and vitrification.

10.2.9 Disposal/Reuse

Disposal is the permanent placement of material that is removed from the site into a permitted and/or appropriate structure or facility. Examples of disposal alternatives include in- or near-water facilities such as confined aquatic disposal facilities or confined disposal facilities, and

upland and off-site landfills. Any off-site disposal facility must be permitted and in compliance with the CERCLA off-site policy (i.e., the facility must also be in compliance with all substantive permit requirements).

Beneficial reuse can provide an alternative to disposal for some dredge material if, after treatment, the residual materials can be used for other beneficial uses such as industrial fill or daily landfill cover.

10.2.10 Combined Actions

As GRAs, combined actions are defined as the use of two or more response actions within a single operable unit or site.

10.3 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS

Remedial technologies and associated process options were identified for each GRA presented in Section 10.2 and evaluated for applicability to Lockheed West Site sediments. The GRAs, technology types, and process options are listed in Table 10-1. These technologies were qualitatively evaluated and screened based on their effectiveness, implementability, and order-of-magnitude costs, the criteria previously described in Section 10.1. This screening evaluation process is not intended to eliminate other process options from possible use. The process is mainly intended to streamline the development of remedial alternatives for more detailed evaluation in the FS. Consistent with CERCLA guidance (EPA, 1988), representative process options are selected to represent each technology type in order to evaluate further and develop cost estimates for the remedial alternatives. Selecting a representative process option does not preclude reexamining other similar process options later in the design phase of the project. The actual remedial systems will be designed, bid, and implemented after EPA has selected a remedy in the ROD for the Lockheed West Site.

Ancillary technologies and process options associated with one or more of the remedial technologies were also identified (Table 10-2). These ancillary technologies have not been subjected to the same screening process but are presented in this document because they offer important considerations in the assembly of remedial alternatives.

10.3.1 Identification and Screening Process

A review of current literature, database, federal guidance documents, and FS documents from other recent CERCLA contaminated sediment sites in the region was conducted to identify potential candidate remedial technologies.

For a particular GRA, identified technologies were qualitatively evaluated on their relative effectiveness, implementability, and cost. Technologies were retained for further evaluation based on the degree to which they satisfied each of these criteria. Each of the retained process options is considered to have the potential to be effective for managing the COCs in the Lockheed West Site sediments and the potential to be implemented given overall Site conditions.

As directed by the CERCLA guidance (EPA, 1988), the screening evaluation is focused on effectiveness factors at this stage with less emphasis on the implementability and cost evaluation. Effectiveness was rated as low, moderate, or high and it considered: 1) the potential effectiveness of process options in handling the estimated areas or volume of media and meeting the remediation goals identified in the RAOs; 2) the potential impacts to human health and the environment during the construction and implementation phase; and 3) how proven and reliable the process is for the contaminants and conditions at the site.

When evaluating implementability, technical feasibility, administrative feasibility, and availability of services and materials have been considered as recommended by EPA (1988) guidance. Technical feasibility includes technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy. Administrative feasibility includes activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-site actions). Availability of services and materials includes the availability of adequate off-site treatment, storage capacity, and disposal capacity and services; the availability of necessary equipment and specialists and provision to ensure any necessary additional resources; the availability of services and material; and availability of prospective technologies. Implementability was generally rated as low, moderate, or high, ranging from difficult implementation (low) to easy (high).

Cost evaluation considered relative direct/indirect capital costs and annual operations and maintenance costs rather than detailed estimates. Comparative costing evaluation excludes assignment of actual dollar values at the technology/process option screening level. Costs of each process were rated as low, moderate, or high relative to other process options in the same technology type.

Technologies that were rated as less effective or technically more difficult to implement relative to others in the same GRA category were dismissed from further evaluation. Technologies providing similar or greater effectiveness and implementability were retained. Cost evaluation played a limited role in the screening of process options; no technology was dismissed from further evaluation due to high cost.

Certain technologies and process options exhibiting potential applicability to the Lockheed West Site have been retained through the screening process but are not assembled into sitewide representative alternatives; these are labeled as "retained for design, not carried forward for detailed analysis in the FS." These technologies are retained for potential incorporation into alternatives in subsequent FS steps, or during design, should further development of the current alternatives demonstrate a need to expand or replace currently assembled technologies.

10.3.2 Site Characteristics Considered During the Identification and Screening Process

The physical characteristics of the site, its history, and the nature and extent of contamination are provided in the *RI/FS Work Plan*, the *Nature and Extent Summary Memorandum*, and in Section 4. Site characteristics considered in the identification and screening process include the following:

- The Lockheed West study area boundaries. The northern boundary is based on the top of the deltaic shelf slope and the contiguous definable extent of risk-driver sediment concentrations above the RBTC or "Bold Study" 95 UCL (Figure 4-44) except for PCBs and cPAHs. The other boundaries that define the study area are also shown on Figure 4-44 and comprise the shore (south), the PSR boundary (west), and the West Waterway OU boundary (east). This study area boundary also encompasses the extent of PCB and cPAH exceedances of the SQS.

- The area designated for potential remedial action shown on the alternatives figures in Section 11 extends from the shoreline at +11.35 feet MLLW to subtidal mudline elevations ranging from approximately -25 to -55 feet MLLW (Tetra Tech, 2008a). The Site boundaries will be finalized in the ROD.
- The tidal range at the Lockheed West Site is approximately 15 feet (Tetra Tech, 2008a).
- Areas adjacent to the berth at Terminal 5 may be subject to vessel wake and propeller scour (Tetra Tech, 2008a).
- Current (and expected future) upland land use is a marine shipping terminal. Anticipated future uses at the Site include potential Port of Seattle Terminal 5 dock expansion to the north along the West Waterway. Currently there are no plans to change the existing uses along the north shore of the Site from temporary moorage; however, the Port has indicated that deep draft moorage (-50 feet MLLW or greater) could be proposed in the future (Port of Seattle, 2010, 2011).
- A federal navigational channel and a state waterway designated under Revised Code of Washington 79.120.010, the West Waterway OU, borders the east side of the site. West Waterway navigational project depth is established by USACE at -34 feet MLLW (NOAA, 2010). The United States and the State of Washington have concurrent jurisdiction over the management of West Waterway. That statute precludes DNR from selling or leasing the waterway. However, other statutes authorize DNR to issue permits, licenses, or easements for uses that do not conflict with the navigational purposes of the waterway. Prior to the issuance of any authorization, DNR will have to obtain USACE concurrence that the use will not conflict with navigation. Though the congressionally authorized project depth for the waterway is -34 feet MLLW, the operational depth is -50 feet MLLW or greater. The Port of Seattle is authorized to develop all waterways within its boundaries under Revised Code of Washington Title 53.
- The sediments consist primarily of silt and sandy silt, although sediments closer to shore comprise more sand and gravel (Tetra Tech, 2008b).
- The major risk drivers for the Lockheed West Site (Tetra Tech and Pascoe, 2009a,b) include cPAHs, arsenic, lead, copper, mercury, TBT, PCBs, and dioxins/furans.

The range of detected surface and subsurface concentrations for the major risk drivers is listed in Table 10-3.

10.4 SCREENING OF INSTITUTIONAL CONTROLS

This section summarizes screening of institutional control GRAs for the Lockheed West Site.

10.4.1 Description

Institutional controls represent non-engineering, passive GRAs intended to affect human activities or protect engineered remedies in such a way as to prevent or reduce exposures to contaminated sediment from occurring and to ensure both the short- and long-term protection of human health and the environment. In its institutional controls guidance (EPA, 2002d), EPA defines institutional controls as non-engineered instruments, such as administrative and/or legal controls, that help to minimize the potential for human exposure to contamination and/or protect the integrity of a remedy. Institutional controls are not meant to be in lieu of cleanup actions; rather, they limit land or resource use by providing information that helps modify or guide human behavior at the site. Additionally, the guidance states that institutional controls play an important role in remedies to help minimize the potential for exposure and protect engineered remedies. They are most often used in conjunction with remedial technologies that supplement engineered remedies and may isolate or leave contaminated sediments in place or in circumstances where concentrations of contaminants in fish or shellfish are expected to pose risks to human health for some time in the future (EPA, 1997c). However, such actions do not reduce the toxicity, mobility, or volume of COCs. Institutional controls range from educational tools and advisories to easements, covenants, deed restrictions, and federal, state, or local use restrictions (EPA, 2000a).

The engineered remediation options (caps and/or dredging) can be designed to take future land use into consideration. At the Lockheed West Site, the Port, DNR, and the Muckleshoot and Suquamish Tribes have all expressed future land use and/or tribal treaty rights for consideration. After the remedial action is designed and implemented, it then may be necessary to “layer” institutional controls onto the remedy to ensure protectiveness of the engineered controls while allowing for fishing and clamming, fishing boat tie-offs, commerce, and navigation. An intent of the Lockheed West project is to minimize the need for institutional controls. The degree of institutional control implementation is typically related to the remedy application area and method. For example, fewer institutional controls are needed for dredging (e.g., possible temporary fish advisories) than for alternatives involving extensive capping). EPA generally consolidates the types of institutional controls available into the following four general

categories: government controls, proprietary controls, enforcement and permit tools, and informational devices (EPA, 2003c). These categories are described below.

10.4.1.1 Governmental Controls

Governmental controls impose land or resource restrictions enforced by federal, state, or local government. These controls include zoning restrictions, ordinances, permits, or other provisions that restrict land or resource use at a site. Government controls almost always have to be adopted and enforced by a governmental entity other than EPA (e.g., state or local governments). Thus, their effectiveness depends in most cases upon the authority and ability of state or local governments to adopt them and enforce them over the long term. There may also be enforcement costs for the state or local jurisdiction (EPA, 2000a).

Government controls can include the permitting of some point source discharges, waterway use restrictions, dredging and backfilling of an authorized waterway, or bans on harvesting fish or shellfish. At the Lockheed West Site, waterway use restrictions may be necessary to ensure the integrity of a remedial alternative where subsurface contamination remains in place (e.g., *in situ* capping). These restrictions may include controls on vessel operations/anchorage/grounding to minimize receptor exposures that could result from disturbing sediment or physically compromising an *in situ* remedial action. Compromising an *in situ* cap may cause contaminated sediment to re-suspend in the overlying water column, settle on the cap, and potentially expose ecological receptors to contaminated sediment that was previously under the cap surface. Example institutional controls related to protecting sediment cap integrity could include the following:

- Restrictive anchorage within in areas that are capped;
- Restrictive grounding of small vessels on the shoreline;
- Restrictions of vessel draft, horsepower, speed, and time in area; and
- Restrictions on piling placement or removal through cap, or special maintenance requirements.

10.4.1.2 Proprietary Controls

Proprietary controls, often referred as deed restrictions, are tools based on property law that are used to prohibit activities that may compromise the effectiveness of the remedy or restrict

activities or future uses of resources that may result in unacceptable risk to human health or the environment. Deed restrictions are a common institutional control used to place restrictions on future site uses or activities that may disturb contaminated sediments (e.g., restrictions on installing underwater utilities, piers, or other construction). They may also be used to provide site access for operation and maintenance activities.

The most common examples of proprietary controls are easements and covenants. As noted in EPA (2000a) guidance, an easement is in general fully enforceable as long as its nature and scope are clear and notice is properly given to the parties against whom the agreements are binding (e.g., by recording the easement in land records).

Restrictive covenants can be used to establish an institutional control where the cleaned-up property is being transferred from the current owner to another party. Enforcement of covenants is subject to state law and enforceable by the holder in the state court with jurisdiction over the property's location. In 2007, the State of Washington adopted the Uniform Environmental Covenants Act (UECA) setting out specific requirements as to how environmental covenants will be used and enforced. Washington State's MTCA generally requires that institutional controls such as restrictive covenants be imposed on contaminated property whenever the remedial action conducted will result in hazardous substances remaining in soil, groundwater, or other media at concentrations that exceed applicable cleanup levels, or when Ecology determines that such controls "are required to assure the continued protection of human health and the environment or the integrity of the interim or cleanup action" (WAC 173-340-440 [4]). The purpose of a restrictive covenant as described in the UECA is to prohibit activities that may interfere with a cleanup action, operation and maintenance, or monitoring, or may result in the release of a hazardous substance that was contained as a part of the cleanup action. Restrictive covenants must be recorded to give adjoining property owners, future purchasers and tenants, and the general public notice of the restrictions on use of the property. Property owners are also required to notify Ecology prior to any lease or sale of the restricted property (WAC 173-340-440[9]). The UECA allows EPA to enforce restrictive covenants without taking a proprietary interest that is prohibited by CERCLA Section 113(j).

10.4.1.3 Enforcement and Permit Tools

Enforcement and permit tools with institutional control components are types of legal tools that include orders, permits, and consent decrees. These instruments may be issued unilaterally or negotiated to compel a party to limit certain site activities as well as ensure the performance of affirmative obligations (e.g., to monitor and report on an institutional control's effectiveness). Where enforcement tools are used to implement institutional controls, they may include provisions of CERCLA Unilateral Administrative Orders, Administrative Orders on Consent, or Consent Decrees. Long-term monitoring as part the final remedy may also be required pursuant to typical Statement of Work requirements from Administrative Orders on Consent or Consent Decrees.

10.4.1.4 Informational Devices

Informational devices are designed to provide information or notification to the public. Community information/education programs serve to enhance awareness of potential hazards associated with site sediments. Similarly, fish and shellfish consumption advisories, which are communicated through signs and educational programs, aim to control the consumption of potentially contaminated resident fish or shellfish and reduce associated human health risks.

Additional informational devices could apply to areas with containment remedies. Placement and maintenance of site information on the State Registry (Ecology's Hazardous Sites list and Site Register) would provide information regarding restrictions on the site-related property.

10.4.2 Evaluation

This section contains the evaluation of the most common institutional control technologies (i.e., community information/educational programs, seafood consumption advisories, and waterway use restrictions) that may be used at the Lockheed West Site.

10.4.2.1 Effectiveness

The effectiveness of institutional controls depends upon the cooperation of the site owners, site users, and the public and on how they are enforced by the relevant agency or governmental entity (e.g., Coast Guard for regulated navigation areas, federal or state government for UECA covenants). When implemented in conjunction with more active technologies, institutional

controls can be effective at assisting in the management of exposure risks for both human and ecological receptors.

Institutional controls are not effective in meeting RAOs for ecological receptors. They are commonly used in conjunction with other technologies to meet the remediation goals identified in the RAOs. There are no potential impacts to human health and the environment during the construction and implementation stage of any of the institutional control technology types or process options discussed above because there will be no associated sediment-disturbing activities.

EPA (2005c) guidance recommends the use of institutional controls in “layers” or in “series” to enhance the protectiveness by using more than one control at the same time with the same goal (e.g., a consent decree and a deed notice). Therefore, it is important to choose the best combination of institutional controls that will be protective of human health and environment. Institutional controls have proven effective and reliable in meeting human health RAOs when designed, implemented, monitored, and enforced effectively with cooperation of site users, owners, and the public.

10.4.2.2 Implementability

Community information/education, fish and/or shellfish consumption advisories and related signage, and vessel operations/anchorage restrictions are technically implementable for the Lockheed West Site. The administration of these controls would require the cooperation of the implementing agencies and local Native American tribes, as well as public acceptance and commitment from the public, site users, and site owners. In general, EPA’s position on these institutional controls is that education and outreach programs should not continue forever because the goal is improvement in fish tissue concentrations throughout the whole of Elliott Bay over time. Typically, a fish or shellfish advisory is not enforceable and, for the greatest effectiveness, multiple parties/agencies will have to participate in the development of such program. During development of fish advisories, the Washington State Department of Health and the local Tribe co-manage the resource and determine the appropriate amount/type of fish and shellfish that can be consumed. The Tribe then manages, regulates, and enforces the harvest for the Tribe on a ceremonial, subsistence, and commercial basis. Figure 10-1 identifies the

ownership and management areas within the Site. The Site includes approximately 7 acres of aquatic land that was acquired by the Port from Lockheed Martin between 1989 and 1992 and approximately 20 acres of aquatic state-owned land managed by DNR and historically leased to Lockheed Martin. Management and ownership status of the site requires coordination between EPA, DNR, and the Port during selection, design, and implementation of the institutional controls. For example, if a conventional cap is part of the remedy, the implementation of long-term maintenance of the cap requires coordination with the Muckleshoot and Suquamish Tribes, Port, and DNR about the implications for future aquatic land use and/or tribal treaty rights (i.e., fishing rights on all usual and accustomed [U&A] areas). If a no-anchor zone designation is to be applied to commercial vessels with anchors that have the capacity to break through the cap and expose contaminated sediments, such an institutional control will be implemented through federal rule-making by the U.S. Coast Guard and the USACE in consultation with DNR. Because the Site is a tribal U&A area, a remedy cannot conflict or restrict tribal treaty fishing rights or other treaty protected rights such as anchorage of tribal fishing vessels or access to aquatic resources. It is the intention of the project to minimize the need for institutional controls to optimize the implementability of the required institutional controls.

On occasion, institutional controls appear to be easy to implement or enforce but some examples in EPA Region 10 suggest otherwise. For example, the Coast Guard has still not implemented a restricted navigation area at the PSR Superfund site more than 5 years after the remedy was completed. The deed restrictions placed on the waterway businesses along the Thea Foss Waterway in Tacoma, Washington, also took almost a year to implement. While posting signs like “no fishing/or limit your fish consumption” is implementable, it may not be considered an “effective” institutional control by EPA. This control is only effective if there is follow-up action by the principal responsible party or a third party (e.g., state or local departments of health) to ensure that people understand and are abiding by the fish advisory.

EPA has recently set forth a strategy for ensuring that institutional controls are successfully implemented at cleanup sites. The strategy includes gathering and entering information in the Institutional Controls Tracking System, evaluating the data generated through the system, prioritizing and conducting site-specific follow up activities, building the capacity to better manage and review information, and coordinating with other interested parties (EPA, 2004c).

This strategy is expected to improve implementability of institutional controls at cleanup sites. The implementability of proprietary controls has also been improved with the adoption of the UECA, which addresses the limitations of common law restrictive covenants by creating a system for maintaining permanent records of environmental covenants and contains procedural requirements for how such covenants are recorded, monitored, and enforced. As noted above, the UECA allows EPA to enforce restrictive covenants without taking a proprietary interest prohibited by CERCLA Section 113(j).

This implementability screening assumes no change from current Site uses.

10.4.2.3 Cost

The cost of implementing institutional controls compared to other GRAs is low. The cost is related to legal and administrative costs of implementation. Costs associated with monitoring of institutional controls and enforcement activities may also be incurred. While the relative cost of implementing institutional controls is low, the cost may become substantially higher than initially anticipated. For example, in EPA Region 9, the Palos Verdes Superfund project is spending $1 million/year to implement a fish advisory and educational outreach program. This may be a low cost compared to a dredging alternative but is significantly higher than most "community information/educational programs" are initially anticipated to be. There are also costs associated with diminishment of commerce and navigation, public access, treaty fishing rights, and other factors as consequences of institutional controls. These costs were not taken into account during this screening process. However, they are acknowledged here to emphasize the importance of considering appropriate types of institutional controls that give reasonable assurance that the site remedy remains protective over time while being consistent with the future use of the site to minimize the indirect costs as mentioned above. Notwithstanding these considerations, institutional controls are in general a low-cost method of managing human health risks associated with contaminated sediment compared to other technology-based cleanup options that involve containment, removal, treatment, or disposal and are potentially appropriate for the Lockheed West Site.

10.4.3 Screening Summary

Institutional controls are important features of many sediment cleanup projects. General categories of institutional controls described above are all retained for further consideration in the FS (Table 10-4). An intent of the remedial design is to minimize institutional controls and not to impact or restrict future aquatic land use and/or tribal treaty rights. The requirements for waterway use restrictions if needed under government controls would be clarified during design depending on the post-remediation water depths. To address waterway use limitations, the process option of monitoring and notification of waterway users was retained for the FS and analyzed under informational devices. Similarly, enforcement tools were also retained under informational devices. Some of the process options overlap to enhance the protectiveness following the EPA (2005c) guidance (e.g., some proprietary controls have government enforcement mechanisms and some informational devices can be related to governmental controls).

10.5 SCREENING OF MONITORED NATURAL RECOVERY TECHNOLOGIES AND PROCESS OPTIONS

This section contains a summary of the description and screening evaluation of MNR technologies for the Lockheed West Site. As discussed in Section 1, Lockheed Martin and EPA agreed that natural recovery as a primary remedial alternative was not likely to meet CERCLA criteria for remedy selection and have therefore focused on active remediation of the Lockheed West Site.

10.5.1 Description

Monitored natural recovery of contaminated sediments relies on naturally occurring physical, chemical, and/or biological processes (e.g., burial, biodegradation, and mixing) to reduce the mobility or toxicity of contaminants over time. The appropriateness of MNR as a remedy is evaluated through a multiple lines of evidence approach used to qualitatively assess the combined action of site-specific physical, biological, and chemical mechanisms to reduce the availability of contaminants (EPA, 2005b). At the Site, the primary basis for considering MNR is the potential reduction in exposure levels by a decrease in near-surface contaminant concentrations through burial and mixing (e.g., bioturbation). Figure 10-2 conceptually shows the MNR process during which, in the long term, sediments become buried and or mixed with

newly deposited sediments, resulting in a reduction in the surface sediment concentrations for the contaminants. Over time, sediments below the mixing layer become buried under a layer of sediment comprising material that is continually being deposited on the surface and sediments that were and are within the mixing/biologically active zone.

Key assumptions associated with MNR under this scenario include a combination of an adequate sedimentation rate and the deposition of material that has lower contaminant concentrations than the existing sediments that will achieve a reduction in surface concentrations to meet the cleanup goal within a specified timeframe. Under the SMS, that timeframe is typically assumed to be within 10 years. In addition, it is assumed that mixing will take place in the biologically active zone. As documented in the *ERA* and according to Ecology (2007, 2008), past studies in Puget Sound have demonstrated that the majority of benthic macroinvertebrates are generally found within the upper 10 centimeters (4 inches) of the sediments. While some species may be found at greater depths below the sediment surface, 10 centimeters is generally assumed to represent a reasonable estimate of the biologically active zone.

Monitored natural recovery technology would include monitoring to assess performance and to confirm the predictions of natural recovery processes.

10.5.2 Evaluation

The screening evaluation for MNR is summarized in this section.

10.5.2.1 Effectiveness

The COCs in Site sediments are generally resistant to biodegradation and dissolution. The primary mechanism for natural recovery at the Lockheed West Site would be burial and contaminant reductionvia sediment deposition.

Observations of recent bathymetric data and knowledge of Site use and dredging history indicate the bottom surface has not changed significantly since the era of historic operations (Tetra Tech, 2009b). This suggests sediment deposition occurs at a relatively slow rate in this location of Elliott Bay. However, no data to evaluate the sedimentation rate were collected as part of the RI so, while sedimentation may be occurring at the Site, the specific rate represents a data gap. Given a presumed slow sedimentation rate and resistance of contaminants of concern to

biodegradation and dissolution, MNR alone would likely have relatively low effectiveness in achieving the RAOs. However, during the design phase if additional data were collected, MNR may be identified as potentially effective in some areas as a component of a combined remedial alternative.

10.5.2.2 Implementability

Monitored natural recovery is technically implementable for Site conditions, although data gaps would need to be filled during design to confirm the sedimentation rate. Resources needed for MNR are readily available from multiple vendors and are procurable through competitive bidding. There are numerous contractors and sufficient skilled labor in the Pacific Northwest to implement a monitoring program for contaminated sediment at the Lockheed West Site.

10.5.2.3 Cost

Monitored natural recovery is generally a lower cost option compared to active remediation that involves ENR, containment, removal, or treatment of sediment. Monitoring costs of MNR may be significant depending on the term and magnitude of the monitoring program. Long-term monitoring costs vary widely depending upon the project expectations, media of concern, and residual risks.

10.5.3 Screening Summary

A summary of the screening of MNR remedial technology and process options is presented in Table 10-5. Monitored natural recovery technology is not considered applicable to the Lockheed West Site as a sole component of a remedy. However, during the design phase MNR may be identified as an appropriate component of a combined remedial alternative, assuming additional data collection confirms an appropriate sedimentation rate. Monitored natural recovery is retained for design but not carried forward into assembly of alternatives.

10.6 SCREENING OF ENHANCED NATURAL RECOVERY TECHNOLOGIES AND PROCESS OPTIONS

This section contains a summary of the description and screening evaluation of ENR technologies for the Lockheed West Site. The application of ENR as a primary remedial alternative in all areas of the Lockheed West Site will not meet CERCLA criteria for remedy

selection. However, ENR may be used as a part of the remedy selection in conjunction with capping or dredging remedial activities, which will be discussed in Section 11.

10.6.1 Description

Description of Typical ENR. Enhanced natural recovery typically has been used to accelerate the MNR process by engineering means, for example, adding a thin layer of clean material over areas with relatively low contaminant concentrations (Figure 10-3a) to speed up, or enhance, the natural recovery processes likely to be occurring at a site (e.g., burial and mixing). The result in the long term (i.e., steady state) is a new mixed surface layer/biologically active zone similar to that for MNR, where deeper sediment becomes buried under a layer that is composed of material that is continually being deposited on the surface, the applied ENR material, and sediments that are or were in the mixing/biologically active zone.

Enhanced natural recovery is considered active management. It differs from capping in that it is not designed to provide long-term isolation. It immediately reduces concentrations of contaminants at the time of application, facilitates the re-establishment of benthic organisms, and minimizes short-term disruption of the benthic community while ongoing recovery processes reduce the bioavailability or toxicity of contaminants in sediments (Merritt et al., 2009). As documented in the *ERA* and according to Ecology (2007, 2008), past studies in Puget Sound have demonstrated that the majority of benthic macroinvertebrates are generally found within the upper 10 centimeters (4 inches) of the sediments. While some species may be found at greater depths below the sediment surface, 10 centimeters is generally assumed to represent a reasonable estimate of the biologically active zone. Assuming the bioturbation activity depth is 5 to 10 centimeters (NRC, 2001) and an approximately 10-centimeter clean layer of sediments is placed during ENR implementation, the long-term steady state equilibrium condition assuming complete mixing of the ENR material and the underlying sediment may reduce contaminant concentrations in the active zone by up to 50 percent through mixing alone. During construction, a more typical clean layer thickness is 15 to 23 centimeters (6 to 9 inches), providing a greater contaminant concentration reduction than noted above. During the FS and design process, an ENR thickness is estimated based on the surface COC so that ENR would result in a surface layer with chemical concentrations below target remediation levels.

Enhanced natural recovery is typically considered where natural recovery processes are occurring but at a rate that is insufficient to reduce risks within an acceptable time frame (EPA, 2005b). However, at this site ENR is not being used to jumpstart the MNR processes, as the data necessary to fully evaluate MNR (e.g., sedimentation rate) were not collected during the RI. Instead, ENR is evaluated by contaminant concentration reduction through biological/physical mixing processes with an assumption of no new sediment deposition (see the discussion below). This accelerated reduction in risk can occur through several processes including bioturbation of clean sediment mixed with underlying contaminants. ENR has been selected as a remedy component at Region 10 Superfund sites including Commencement Bay (Tacoma, Washington), Eagle Harbor (Bainbridge Island, Washington), the Manchester Annex site (Kitsap County, Washington), the Puget Sound Naval Shipyard (Kitsap County, Washington), and the Ketchikan Pulp site (near Ketchikan, Alaska) (Thompson et al., 2003).

Description of ENR Effectiveness Assumptions for the Lockheed West Site. For the Lockheed West Site, the application of ENR is focused on addressing areas where the surface sediments have relatively low levels of contamination (i.e. less than 2 times the SQS) present that require some remedy action. In addition, the concentrations in the underlying near surface (e.g., 1-2 feet) sediments in these areas are generally less contaminated than the surface sediments. Though sedimentation is likely occurring at the Lockheed West Site, the data necessary to fully evaluate sedimentation rates were not collected during the RI, so the long-term sediment deposition (as described for typical ENR applications) is not considered to contribute to the remedy in the evaluation of ENR for the alternatives developed in Sections 11 to 13. This results in a conservative estimation of ENR effectiveness when ENR is applied as part of the remedy alternatives. Determination of the long term effectiveness (i.e., at steady state conditions) of ENR for the Lockheed West Site would be as follows. After application of a layer of clean material approximately equal to the thickness of the biologically active zone of 10 centimeters (4 inches) and through bioturbation and other mixing mechanisms (e.g. anchor drag), a fully mixed layer of surface sediment comprising one half of the clean applied material and one half of the existing surface sediment would result. This process is conceptually shown in Figure 10-3b in which a mixing layer of 20 centimeters (8 inches) is assumed, which is twice as deep as the documented biologically active zone noted above. This is a conservative assumption as it overestimates the resulting surface sediment concentration. This layer over time becomes fully

mixed and the resulting sediment concentration is approximately 50 percent of the initial sediment concentration prior to ENR. Existing sediments deeper than 10 centimeters (4 inches) would be buried under this mixed surface layer and below the nominal mixing zone.

Description of ENR Construction Assumptions for the Lockheed West Site. The evaluation of ENR in the alternatives as noted above used the application of a 4-inch-thick clean layer; however, as discussed further in Section 11, ENR technology typically involves placement of a nominal 6 to 9-inch clean sediment layer. Assumptions used for construction include placing up to 12 inches of clean sediment over an area to achieve a minimum 6-inch layer. Implementation of ENR under these conditions would provide a greater contaminant concentration reduction than noted above. Figure 10-3c shows a more likely scenario for the Lockheed West Site where a nominal 6-inch layer of ENR material is placed at the surface and, assuming the same 8-inch mixing zone discussed above, mixes with the top 2 inches of existing contaminated sediments. The 8-inch mixing/biologically active zone is a conservative depth since it is twice as deep as the biologically active zone assumed for Puget Sound. In fact, it is likely that less than 2 inches and potentially none of the existing contaminated sediment becomes mixed into the surface layer. In addition, it is likely that over the long term, some limited sediment deposition will occur at the Site and this deposited material will make up some small fraction of the long-term surface layer. If these assumptions had been used in the evaluation of ENR for the Lockheed West Site, estimated steady-state sediment concentrations would have been lower and application of ENR could have been found to be effective in more areas of the Site.

An ENR technology would include monitoring to assess performance and to confirm the predictions of enhanced natural recovery placement.

10.6.2 Evaluation

The screening evaluation for ENR technology is summarized in this section.

10.6.2.1 Effectiveness

The COCs in Site sediments are generally resistant to biodegradation and dissolution. The primary mechanism for ENR at the Lockheed West Site would be burial and contaminant

concentration reduction via sediment deposition along with bioturbation of the placed ENR layer with the shallow underlying sediment.

Enhanced natural recovery alone may have low effectiveness in achieving the RAOs in all areas of the Lockheed West Site. However, in areas where hazards presented by contaminated sediment are relatively low (e.g., COC concentrations equal to or less than two times the SQS) and the underlying sediment concentrations are generally lower, ENR is anticipated to be moderately to highly effective in achieving RAOs immediately, by reducing COC concentrations in the surface layer, and in the long term, primarily due to contaminant concentration reduction through mixing. As discussed above, rather than placing a 10-centimeter (4-inch) clean layer during construction, a more typical clean layer placement thickness is 15 to 23 centimeters (6 to 9 inches), potentially providing a greater contaminant concentration reduction than the 50 percent reduction illustrated above. Thus, applying a 50 percent COC concentration reduction estimate to the technology is a conservative estimate of its effectiveness.

10.6.2.2 Implementability

Enhanced natural recovery is technically implementable for Site conditions. Enhanced natural recovery will require substantive compliance with Sections 404 and 401 of the Clean Water Act and Endangered Species Act (ESA) consultation. Resources needed for ENR are readily available from multiple vendors and are procurable through competitive bidding. There are numerous marine contractors, suitable construction equipment, and sufficient skilled labor in the Pacific Northwest to implement a thin layer placement over the sediments and to perform a monitoring program for contaminated sediment at the Lockheed West Site.

10.6.2.3 Cost

Enhanced natural recovery is generally a lower cost option compared to active remediation that involves containment, removal, or treatment of sediment. Enhanced natural recovery costs generally range from low to moderate compared to other technology costs, depending on the costs for placement of a thin layer of clean granular material. Use of reactive media (activated carbon, organoclay, etc.) substantially increases raw materials costs. Monitoring costs of ENR may be significant depending on the term and magnitude of the monitoring program. Long-term

monitoring costs vary widely depending upon the project expectations, media of concern, and residual risks.

10.6.3 Screening Summary

A summary of the screening of ENR remedial technology types and process options is presented in Table 10-5. Enhanced natural recovery technology is not considered applicable to all areas of the Lockheed West Site as a sole component of a remedy. However, ENR is considered appropriate as a component of a combined remedial alternative. Enhanced natural recovery is retained and carried forward into assembly of alternatives.

10.7 SCREENING OF CONTAINMENT TECHNOLOGIES

This section summarizes the description and screening evaluation of containment technologies for the Lockheed West Site.

10.7.1 Description

There are three general types of *in situ* caps: conventional sediment caps, composite caps, and reactive caps.

Conventional sediment capping is generally the most straightforward and among the least intrusive sediment remediation techniques. The technique involves placing clean capping material over the areas of contaminated sediment to reduce the risk of human or biotic contact with contaminated sediment through physical isolation, stabilization, and chemical isolation mechanisms (EPA, 2005b). Conventional caps are constructed of granular material, such as clean sediment, sand, or gravel, and may include an armor layer to reduce disturbance of the cap materials and a habitat mix layer for habitat improvement. A more complex cap design (generally referred to as a composite cap) can include geotextiles, liners, and other permeable or impermeable elements in multiple layers. Reactive caps incorporate reactive media to attenuate the flux of contaminants (e.g., organic carbon).

10.7.1.1 Conventional Caps

Conventional sediment caps are a well-developed and documented cleanup alternative in the Pacific Northwest and nationally. EPA endorses this method for its environmental protectiveness (EPA, 1998, 2005b).

Capping isolates areas of contaminated sediment and establishes conditions for the creation of a new benthic habitat. Conventional caps typically consist of granular materials (clean sediment, sand, or gravel) to achieve these goals. Other layers may be added to enhance the physical or chemical isolation capacity. For example, riprap can be used to stabilize a cap and underlying sediments, and cobbles can be used minimize bioturbation from burrowing organisms. Typically, up to 3 feet of clean material (EPA, 2005b) would be used for a cap; however, the thickness of the cap would be determined during remedial design based on evaluation of various factors including bioturbation, consolidation, erosion, operational considerations (such as propeller scour), and chemical isolation. The USACE provides guidance for determining the thickness of the cap during design (Palermo et al., 1998; Clarke et al., 2001). The cap thickness can be increased to maintain contaminant isolation and accommodate burrowing organisms, whereas stabilization material such as riprap and cobbles can be used to dissuade these organisms from inhabiting the cap. Conventional caps also need to be designed to meet site-specific uses. At the Lockheed West Site, the caps will need to be designed to support clamming and fishing activities because the Site is a tribal treaty U&A area. Therefore, additional capping material may need to be placed to support the benthic infauna necessary for fish foraging. In this FS, a preliminary cap thickness was estimated following the USACE guidance to ensure that the cap thickness and other land use constraints and resource opportunities can co-exist. Other cap design considerations include geotechnical concerns such as bearing capacity of underlying sediments, stability of caps placed on slopes, and the static and seismic stability of overall sediment deposits. The Lockheed West Site is subject to seismic activities. Therefore, earthquake-induced hazards to the cap and interpretation of such hazards in terms of the expected risk and the repair requirements were evaluated and incorporated into this FS (see Appendix H).

The performance of the cap is typically monitored to ensure the physical and chemical isolation of contaminated sediments and for recovery of the benthic system. Physical monitoring activities may include bathymetry, sub-bottom profiles, side-scan sonar, and sediment profile imaging to

assess cap integrity. Chemical monitoring activities may include surface grab samples and subsurface cores to assess contaminant migration. Biological monitoring activities may include benthic community evaluation and sediment toxicity tests to evaluate the effectiveness of the cap at reducing toxicity to sediment-dwelling organisms. Sediment profile imaging may be used as a surrogate for more intrusive sampling and toxicity testing to characterize overall benthic habitat quality.

During cap construction, there are some short-term water column impacts (e.g., increases in turbidity, total suspended solids, or dissolved oxygen), but best management practices with water quality monitoring are used to address these impacts.

Implementability issues generally associated with conventional capping include obtaining appropriate cap thickness over the entire area of contaminated sediment, placing the capping material without displacing sediment, and maintaining long-term cap integrity. Several methods of cap installation are used to address these issues including the following:

- **Surface discharge using conventional equipment—**Cap material released at the water's surface using conventional equipment tends to descend rapidly to the bottom with minimal short-term losses to the overlying water column. Therefore, conventional equipment can be considered for placement of capping material if the bottom spread and water column dispersion resulting from such a discharge are acceptable.
- **Surface release from barges**—Sediment is slowly released from a split-hull barge or pushed off the side of a barge moving slowly over the area of contaminated sediment.
- **Submerged diffuser**—Capping material is pumped through a submerged hydraulic pipeline to the contaminated area. The submerged diffuser is then used to reduce the velocity at the point of contact, minimizing re-suspension of contaminated sediments.
- **Hydraulic washing**—Clean sediment is washed off a barge using large water hoses. This method allows capping material to fall onto the contaminated area in a controlled manner, reducing re-suspension and encouraging deposition of clean material on top of, rather than displacing, fine, soft sediments. Hydraulic washing has been used effectively in shallow water where bed material was predominantly sandy silt and silty sand.
- **Hydraulic pipeline with baffle box**—This method is much like a submerged diffuser, with a baffle box working to reduce the velocity of pumped sediment. However, the

baffle box works with a floating pipeline and allows the capping material to fall slowly through the water column.

- **Direct mechanical placement**—A mechanical dredging device such as a clamshell or backhoe is used to place capping material near the bed surface. Alternatively, capping material may be cast from the water surface using a clamshell or backhoes and allowed to settle to the bottom.

10.7.1.2 Composite Caps

Composite caps are essentially a variant of conventional sediment caps and generally consist of granular material. They may be constructed of different types of granular material and in multiple layers. They may also contain materials such as geotextile or geomembrane liners to address stability concerns or enhance isolation of contaminated sediments.

10.7.1.3 Reactive Caps

Reactive capping is an innovative technology that can provide greater effectiveness to *in situ* sediment management by increasing resistance to contaminant flux to the water column. Reactive caps integrate reactive media to promote chemical and/or biological immobilization or degradation of contaminants, as well as provide a physical barrier to contaminants below.

Some of the reactive materials, such as activated carbon and organoclay, have been demonstrated to reduce sediment contaminant concentrations at full-scale implementations, while others, such as zero-valent iron and polymers, are still in the research phase. Reactive materials that are currently demonstrated are generally inert ingredients that sequester (or bind) contaminants. The type of contamination at a site may dictate the type of reactive material used in a sediment cap. Activated carbon and other carbon sources are appropriate for sequestering dissolved organic contamination, while phosphate is useful for addressing metals. Applications of both sediment amendment and reactive caps utilizing activated carbon as a sorbent are well-documented in several remediation projects including the Grasse River, Anacostia River, Stryker Bay, and Hunters Point Naval Shipyard for reducing bioavailability of persistent organic chemicals in sediments (McDonough et al., 2007; Madalinski, 2008). Recent monitoring data at Hunters Point Naval Shipyard in San Francisco, California, found that an activated-carbon amended sediment layer could be stable for several years. There was no significant impact on the organisms present at the site, and the technology was proven to be a less-expensive alternative to dredging and

other remediation approaches (Ghosh et al. 2011). Organoclay was applied in bulk and as organoclay mats at the McCormick and Baxter Superfund site in Portland, Oregon, in 2004 and 2005. To date, these applications applied one type of reactive material to treat one class of contaminant and have typically been deployed as relatively thick layers (6 to 12 inches) over the bottom (SERDP, 2009). At Anacostia River, coke breeze, apatite, and organic carbon amended caps were used for field-scale demonstration to address PCBs, PAHs, and metals contamination.

In August 2008, the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) conducted a workshop focused on research and development needs related to the bioavailability of contaminants in soils and sediments. As a result of this workshop (SERDP and ESTCP, 2008), critical priorities were established for researching *in s itu* remedies to reduce bioavailability of contaminants in sediments. These areas were identified as follows:

1. Demonstrate effectiveness and permanence of *in s itu* remedies through field studies. Although several technologies for both capping and *in s itu* treatment have been developed, demonstration and validation of the effectiveness and permanence of these remedies are still needed.
2. Develop methods for predicting and monitoring the effectiveness and permanence of *in situ* remedies.

A better understanding of the effect of black carbon and system dynamics on bioavailability is expected to aid in the development and assessment of organic contaminant remedies. Pursuant to SERDP and ESCTP's workshop, there is ongoing research to develop optimal mixtures of reactive materials or amendments to treat a variety of contaminants at a site and demonstration and long-term effectiveness and permanence of these remedies (SERDP, 2009).

10.7.2 Evaluation

This section includes a summary of the evaluation of containment technologies for the Lockheed West Site.

10.7.2.1 Cap Decision Factors

Physical site conditions influence the selection and implementability of sediment caps. For instance, sediment caps may result in bed elevation changes that result in unacceptable impacts

to navigation, floodplain, or ecological habitat. Conventional sediment caps require underlying sediments that have sufficient bearing strength to support the cap. Additionally, sediment caps may not be stable in areas with steep bed slope or highly erosive hydrodynamic conditions. In areas where underlying sediments may contain extensive amounts of debris, capping may be more effective than removal actions as indicated in a recent National Research Council (NRC) report (NRC, 2007). Favorable site conditions for a removal action include little or no debris.

The NRC (1997) report provided the following decision factors that should be evaluated for a conventional sediment cap:

- Contaminant sources have been sufficiently abated to prevent recontamination of the cap.
- Contaminants are of moderate to low toxicity and mobility.
- MNR is too slow to meet RAOs in a reasonable time. In Washington State, a reasonable time for MNR is 10 years.
- Cost or environmental effects of removal are very high.
- Suitable types and quantities of cap materials are available.
- Hydrologic conditions will not compromise the cap.
- Bioturbating infauna will not compromise the cap.
- Weight of the cap can be supported by the original bed.
- Cap is compatible with current or future waterway uses.
- Site conditions are not favorable for complete removal of contaminated sediment.

Another decision factor for selection of a sediment cap as part of the proposed remedy is the requirement for long-term monitoring of cap integrity, maintenance and repair of the cap under hydrodynamic forces and seismic events, and associated costs.

10.7.2.2 Effectiveness

Conventional and composite capping technologies are effective in achieving the RAOs for all Site COCs. A reactive cap containing a single reactive media type may be effective at achieving RAOs for a particular COC, but may not be effective for a suite of multiple COCs with varying characteristics. A reactive cap containing multiple reactive media has yet to be implemented for a site with a broad suite of COCs. Due to the limited number of applications to date and their

relatively recent construction, reactive caps, although potentially promising, do not have any long-term effectiveness data against which to evaluate chemical isolation (RETEC, 2005b; SERDP, 2009; SERDP and ESTCP, 2008). In a recent publication, it was noted that although amended sediments are showing promising results, regulators remain cautious because the contaminant is not removed; instead, the exposure risks are decreased by contaminant binding to sediment. Further ongoing research will support scientifically defensible evaluation of potentially applicable *in situ* remedial methods (Ghosh et al., 2011).

10.7.2.3 Implementability

All capping technologies and process options are technically implementable at the Lockheed West Site. With respect to administrative implementability, the primary institutional or administrative issue of capping relates to land ownership and requirements for long-term Site use and cap monitoring. Institutional controls would be required with any capping alternative, including restrictive covenants, deed or use restrictions, potential waterway use restrictions for activities that could disturb a cap, and a commitment to a long-term operation and maintenance plan. Capping will require substantive compliance with Sections 404 and 401 of the Clean Water Act and ESA consultation. There are numerous marine contractors, suitable construction equipment, and sufficient skilled labor in the Pacific Northwest and along the West Coast to execute a contaminated sediment capping project. Resources for the capping are available from multiple vendors and procurable through competitive bidding. Conventional sediment caps have an established history of successful implementation in Puget Sound. The draft LDW FS (AECOM, 2009) identifies and describes regional capping projects.

10.7.2.4 Cost

Costs for capping are moderate compared to other remedial technologies and process options such as dredging, treatment, and disposal. Costs are influenced by the required thickness of cap and complexity of design (e.g., multiple layers or materials), any reactive media used (e.g., activated carbon), long-term monitoring, maintenance, repair requirements, and implementation of requisite institutional controls. The costs of composite and reactive caps are moderate to high compared to the conventional cap.

10.7.3 Screening Summary

All capping technologies have been retained for consideration in the FS and design. Composite and reactive caps, however, have not been carried forward into the assembly of alternatives because not enough study has been completed at this stage of the RI/FS process to justify their incorporation. During the FS and remedial design phase, a composite cap will be considered if a need is identified to enhance isolation or address stability concerns; a reactive cap will be considered to enhance the effectiveness of the cap by reactive materials. Table 10-6 summarizes the screening of containment technologies.

10.8 SCREENING OF REMOVAL TECHNOLOGIES

This section includes a summary of the description and screening evaluation of removal technologies for the Lockheed West Site.

10.8.1 Dredging Technologies

Dredging is the most common way of removing contaminated sediment from a body of water. For dredging projects, several site-specific characteristics must be considered including the depth of the water column, volume of material to be removed, width and depth of the dredge cut, firmness of the sediment, potential presence of protected or beneficial habitat, and the presence of debris. Three types of dredging including mechanical dredging, hydraulic dredging, and hybrid/specialty dredging are explained below.

10.8.1.1 Mechanical Dredging

A mechanical dredge uses various types of buckets to excavate the bottom material and raise it to the surface for disposal. Mechanical dredges are classified according to the size, style, action of the bucket, and how the bucket is connected to the dredge. Most mechanical dredges are mounted on barge hulls. Movement of the barge is by tug, walking spuds, or use of a winch on anchor cables. Common mechanical dredges include the clamshell, dragline bucket, backhoe, dipper, and bucket ladder.

Bucket Types

The clamshell bucket is widely used throughout the world. It is a cable-operated bucket, typically with a rounded bottom. The round bottom results in an irregular, ridged dredge surface. Generally, multiple passes are required to achieve adequate removal.

A more recent technology, specifically developed for remedial actions, is the environmental bucket. This type of bucket is designed to make a level cut and has seals to minimize sediment loss. Environmental buckets have been shown to be more effective in loose sands and low-solid soft sediments with little or no debris. They have been shown to pose difficulty in cohesive sediments, often requiring rinsing during operations to remove cohesive materials that collect on the bucket (RETEC, 2005b). Geologic cross sections, derived from soil borings taken from offshore and upland portions of the Lockheed West Site, indicate the presence of layers of sand, silty sand, and occasionally silt. One boring on the Site indicated "over consolidated" while other borings indicated only low-density sediments (Tetra Tech, 2008a). Recent grain size distribution data indicate that on average surface and subsurface sediments contain 62 percent sand and 35 percent fines (silts and clay), whereas intertidal sediments contain approximately 81.5 percent sand and 1.5 percent fines. Environmental buckets are potentially applicable to the Lockheed West Site low-density silts and sands.

Data for bucket dredge production show typical dredged sediment resuspension concentration of 30 percent to 60 percent with 1- to 5-minute cycle time and 0.2 to 0.9 percent sediment loss (Hayes and Wu, 2001). A demonstration study on bucket dredge comparison at Boston Harbor showed that the conventional bucket produced the highest amount of sediment resuspension spread throughout the water column. Use of the Cable Arm environmental bucket appeared to reduce sediment resuspension in the water column; the observed depth averaged turbidity was 46 percent less than observed for the conventional bucket. The enclosed bucket had the lowest overall turbidity and substantially less in the middle of the water column. Observed depth-averaged turbidity for the enclosed bucket was 79 percent less than observed for the conventional bucket (Welp et al., 2001).

10.8.1.2 Hydraulic Dredging

The main component of a hydraulic dredge is a pump used to move the dredged material. The pump is usually mounted on a barge, but may be located near the submerged excavation end of the dredge. A suction pipeline supplies the dredge material to the pump. A variety of dredging equipment is available for loosening and excavating the sediment at the suction end of the pipeline, including cutter head, bucket wheel, dustpan, auger, and hopper dredges. A discharge pipeline transports the material from the discharge end of the pump to an intermediate or final disposal site.

10.8.1.3 Hybrid or Specialty Dredging

Specialty dredging technologies have developed in response to the demand for sediment remediation and environmental cleanup over the last decade. These specialty dredges may combine aspects of both hydraulic and mechanical dredges. The Bonacavor Hydraulic Excavator, AMPHIBEX, Dry Dredge, Crawl Cat Cutter Suction Dredge, and Vic Vac are some of these innovative dredges.

- The Bonacavor Hybrid Dredge combines a hydraulic pump with a mechanical backhoe. The Bonacavor is a hybrid dredge combining a backhoe bucket excavator with a sediment pumping unit for discharging the material through a pipeline. The sediment pumping unit consists of a hopper and pump connected to a discharge pipeline.
- AMPHIBEX is an amphibious excavator equipped with a bucket for mechanical dredging and a hydraulic pumping bucket to increase the equipment efficiency by allowing a greater percentage of solids to be pumped in the form of slurry. The AMPHIBEX is versatile in its portability in being transported by flat bed truck and ability to move over ground, in shallow water, and in deeper water under its own power.
- Dry Dredge by DRE Technologies is a barge-mounted hybrid dredge that integrates a closed-bucket mechanical dredge with a positive-displacement pump for high-solids dredge material transport.
- The Crawl Cat Cutter Suction Dredge, developed by the Dutch dredge developer IHC Holland, is essentially a hydraulic cutterhead dredge with legs. The Crawl Cat is an amphibious dredge in that it can work as a floating dredge, on tide flats, and along shorelines.

- The Vic Vac is a proprietary hydraulic dredge developed and owned by J. F. Brennan Company that operates like a large vacuum cleaner. This equipment is capable of very thin dredge cuts and is designed to remove thin sediment deposits and clean up residuals left behind after bulk sediment dredging.

10.8.2 Excavation Technology

Excavation refers to the removal of sediments in the absence of overlying water. This often involves the use of conventional excavating equipment and is generally restricted to removal of contaminated sediment and debris in shallow-water environments, dry excavations (areas that are bermed and dewatered for access by land-based equipment), or during low tides. Dewatering of an area for excavation may involve hydraulic isolation/removal of surface water using 1) earthen dams, 2) sheet piling, or 3) rerouting the waterbody using dams.

Excavation provides several advantages over working in the water when the tides are in and the land is submerged. These advantages include the following:

- Allows operators to see the work area and accurately place the bucket to ensure complete removal of the impacted material.
- Allows the operators and oversight staff to see the excavated face and adjust the depth of excavation based on observed conditions.
- Maintains the material to be removed in an intact state, and avoids the potential for creating a soupy mix of sediment and water that can be difficult to capture in the excavator bucket.
- Minimizes the potential to entrain impacted material in the water column.

For the Lockheed West Site, excavation of nearshore areas could be conducted by either operating low ground pressure excavation equipment during low tides, operating excavation equipment from a barge so no shore access would be needed, or isolating an area using sheet piling, earthen dams, cofferdams, or inflatable dams and pumping the area dry. A cofferdam holds back water and allows work to be done inside under dry conditions. The construction industry is able to build mega-cofferdams to accommodate infrastructure developments. For instance, the San Vincent low-level outlet cofferdam (near San Diego) is currently being built 111 feet tall to increase water storage for the area.

At the Lockheed West Site, access to Port property for excavation activities (e.g., excavators and possibly short-term containment of excavated material and debris) conducted from shore-based operations will have to be coordinated under the Port's Homeland Security requirements.

10.8.3 Management of Residuals

All in-water dredging or excavation technologies leave some contaminated sediment behind after completing removal actions. This residual contamination, or residuals, may result from a number of factors including incomplete characterization, inherent imprecision of dredging equipment, and material re-suspended during dredging or excavation that settles back to the bottom.

Residuals may be controlled to a degree through careful selection of type and size of dredge equipment, skill and experience of dredge operator, and control of speed and position of dredging or excavation equipment. Additional control may be gained through use of high-resolution bathymetric surveys (pre- and post-dredge), and use of computer-aided dredge tracking software (e.g., WINOPS or DREDGEPACK).

Regardless of controls implemented, post-dredge residuals are likely to occur. Additional residuals management procedures include post-dredge verification sampling to characterize post-dredge conditions, placement of sand layer to provide immediate contaminant concentration reduction and facilitate natural recovery, and placement of an isolation cap, if appropriate or needed. An appropriate selection of residuals management actions would be based on an evaluation of site-specific conditions.

10.8.4 Evaluation

This section presents a summary of the evaluation of removal technologies for the Lockheed West Site.

10.8.4.1 Effectiveness

Mechanical and hydraulic dredging and excavation technologies are all effective in achieving the RAOs. Hydraulic and specialty dredging equipment entrains a larger volume of water than does a mechanical dredge into dredged sediments that must be subsequently managed. A wide range of percent solids for hydraulic dredges is reported, but 5 percent solids can be expected for most environmental dredging projects whereas mechanical dredging produces near *in s itu* solids

content (EPA, 2005b). Hydraulic and specialty dredging is generally more effective than mechanical dredging in less dense sediments (greater water content). The nature and extent of debris also may greatly limit the effectiveness of hydraulic dredging. The amount of debris known or thought to be at the Lockheed West Site is presented in the *RI/FS Work Plan*. From observations of the Site, review of recent high-resolution bathymetry, and examination of aerial photos, several structures and debris are located along the shoreline of the Lockheed West Site.

In addition to debris, there are historical piers and a shipway that were associated with the operations of the former shipyard site that could interfere with dredges, particularly hydraulic dredges. During redevelopment of the upland container facilities for Terminal 5, the Port constructed a sheet pile bulkhead across the apron of the former shipway in the western portion of the Site and many pilings associated with this structure remain in place at the shipway location. Tetra Tech observed numerous apparent debris piles in the area of the former drydocks and multiple pilings on the seafloor throughout the site (Tetra Tech, 2008a). A recent report published by the NRC on the effectiveness of dredging at Superfund mega-sites noted that some sites exhibited conditions that are more conducive to dredging, less prone to releasing contaminants, and less likely to result in residual contaminated sediment after dredging (NRC, 2007). One of the favorable site conditions noted was little or no debris present. The debris at the Lockheed West Site would not preclude hydraulic dredging; however, an initial debris sweep would likely be required in areas that have debris.

Mechanical dredge equipment is particularly effective in removing stiff or dense sediments. It is most suitable for removal of gravel, dense sand, and very cohesive sediments such as clay, glacial till, peat, and highly consolidated silts. Mechanical dredging minimizes the volume of sediments and additional water to be managed. Excavation technologies are effective for shoreline areas and shallower intertidal areas that are partially exposed during periods of low tides; however, overall applicability is limited due to the limited area for which this technology may be appropriate or effective. Excavation equipment may be additionally effective for removal of debris in certain areas. As also noted by EPA, mechanical equipment is the only approach for debris-removal passes. Cutterhead, plain suction, horizontal auger, and pneumatic specialty dredge heads are subject to clogging by debris and are incapable of removing larger pieces of loose rock and larger debris. Loose rock and large debris can also cause inefficient sediment

removal. The presence of logs and large debris may present dangerous conditions for diver-assisted dredging. Although divers can remove sediment from around large debris or rocks, this type of operation is inefficient (EPA, 2005b).

10.8.4.2 Implementability

All dredging technologies described above are technically implementable at the Lockheed West Site. The factors affecting effectiveness also influence implementability. Weighing into the consideration of removal technologies is the availability of equipment and skilled operators. In general, mechanical dredge equipment (and experienced operators) is more widely available in the Puget Sound region than hydraulic or hybrid dredge technologies. Hydraulic dredging requires an initial debris sweep, upland processing facilities (e.g., water treatment facility or nearshore CDF) for processing of generated sediment/water slurry. Under some conditions (e.g., low-density sediments) mechanical dredging may result in greater resuspension to the water-column.

With respect to administrative feasibility, dredging will require substantive compliance with Sections 404 and 401 of the Clean Water Act and ESA consultation. Any off-site disposal of dredged material must be at a landfill that meets EPA criteria. All generator requirements related to the off-site transport and disposal of the dredged material must be met. In addition, access to Port property and compliance with the Transportation Worker Identification Credential program will require coordination with the Port.

Resources for these removal technologies are available from multiple vendors and procurable through competitive bidding. There are numerous marine contractors, suitable construction equipment, and sufficient skilled labor in the Pacific Northwest and along the West Coast to execute a contaminated sediment removal project.

10.8.4.3 Cost

The cost of a removal action is higher than for other GRAs due to costs for confirmation sampling and ancillary technologies associated with removal such as transport and disposal of sediments, entrained water treatment, and residuals management. The cost for mechanical dredging is high. Operator skill, water depths, requirements to minimize sediment loss, or re-

suspension (among other factors) influence dredge cycle-time (i.e., the time required to capture and release one bucket load of sediment), which is a critical cost factor for mechanical dredging.

Excavation approaches incorporate moderate costs when conducted at shoreline areas or during periods of low tide. If excavation approaches are used in conjunction with dewatering methods (e.g., cofferdams), then costs may be much higher. Costs for hydraulic dredging are moderate to high. Hydraulic dredging costs are influenced by the space and resources required for handling and processing of dredged sediments as well as treatment of decant water produced during dredging. A cost comparison analysis of installation of cofferdam followed by excavation versus treatment of entrained water produced by hydraulic dredge could be performed in the design phase to evaluate the feasibility of the technologies.

Dredging equipment and approaches are normally evaluated in the FS phase so that implementability and effectiveness of the dredging component can be evaluated and cost estimates can be developed for purposes of remedy selection. In the remedial design phase, more detailed evaluations of dredging equipment and approaches are conducted so that designs and cost estimates can be refined and plans and specifications can be developed for project implementation. The dredging contractor usually makes the final selection of specific equipment and approaches for the project execution phase (Palermo et al., 2008). Contaminant release rates due to sediment resuspension have a direct impact on meeting water quality standards, and control of contaminant release can greatly impact production rates and project costs (Palermo et al., 2008).

10.8.5 Screening Summary

All removal technologies have been retained for the FS. Hydraulic and hybrid dredging have not been carried forward into the assembly of alternatives at this time. Mechanical dredging is currently selected as the representative process option to address the project RAOs because it has been successfully used at other Pacific Northwest projects and is readily available. Excavation technologies are anticipated to have applicability in both shoreline and intertidal areas. Excavation technologies may also be used for debris removal, if needed. Table 10-7 summarizes the screening of removal technology types and process options.

10.9 SCREENING OF ANCILLARY TECHNOLOGIES

The ancillary technologies and process options presented below are generally associated with one or more of the remedial technologies identified in preceding sections. These ancillary technologies have not been subjected to the same screening process but are presented here because they offer important considerations in the assembly of remedial alternatives. Screening of ancillary technology types and process options is summarized in Table 10-8.

10.9.1 Dewatering

Removed sediment almost always requires dewatering (either by gravity or by mechanical equipment) to produce a material that is more easily handled. Dewatering may also need to be conducted to meet landfill disposal or transport requirements, to minimize the weight and cost of material transported and disposed of, or as part of processes to separate sand from fine material fractions. Dewatering will require management and potentially treatment of wastewater prior to discharge to either a sanitary sewer or to site surface water. As with all construction activities, dewatering processes would likely incorporate best management practices to protect air and surface water quality, as deemed appropriate during design.

10.9.1.1 Description of Dewatering Process Options

There are two types of dewatering process options, mechanical and passive as summarized below.

Mechanical Dewatering

Typical mechanical dewatering processes include centrifugation, filter presses, belt presses, or hydrocyclones. These technologies physically force water from sediment. These processes are described in detail in the report *Identification of Candidate Cleanup Technologies for the Lower Duwamish Waterway Superfund Site* (RETEC, 2005b).

Passive Dewatering

Passive dewatering relies on gravity settling of suspended sediment particles and passive drainage of clarified water from the sediments. There are many passive dewatering approaches. The process can occur in bermed ponds or lagoons. The process may also occur on haul barges outfitted with side drains or baffles to allow for overflow of clarified water. Alternatively,

sediment/water slurry may be pumped into geotextile bags (e.g., Geotubes, a type of passive filtering device) and allowed to gravity drain.

10.9.1.2 Other Considerations

Other considerations for evaluating and selecting dewatering methods may include the following:

- Estimated volume of water generated by removal technology (e.g., the lower the volume of water generated, the easier and more cost-effective the dewatering process),
- Optimum water content of dewatered sediment (e.g., the lower the water content, the more cost-effective the material transport and disposal),
- Dredge production and rate, and
- Upland or barge staging area space limitations.

During the FS phase, these considerations for dewatering methods will be evaluated with respect to project needs, the duration of the project, and transport needs. Timely completion of the project; the need to meet performance standards for resuspension, release, and residuals; and compatibility among dredging, transport, treatment, and disposal requirements are not always mutually achievable. These considerations should therefore be appropriately balanced in the project design. A range of production rates may be calculated for a range of dredge sizes, and then the numbers and sizes of dredges can be selected to meet the performance standards or desired project duration (Palermo et al., 2008).

10.9.2 Wastewater Treatment

Requirements for and methods used to provide wastewater treatment are driven by the water quality criteria for the discharge receiving system, such as sanitary sewer systems or site surface water. Sanitary sewer systems have additional limitations on quantity, or flow rate, of discharge based on the capacity of the system.

If required, wastewater treatment consists, at a minimum, of gravity sedimentation potentially followed by filtration steps, such as sand filtering. Further processing steps to substantively comply with Clean Water Act/NPDES requirements such as treatment with granular activated

carbon or ozonation, would be evaluated based on the anticipated quality of the process water relative to discharge requirements.

10.9.3 Transportation

All remedial alternatives incorporating removal actions will also require transportation or conveyance methods for the removed sediment. Removed sediment can generally be transported via barge to a shoreline transfer facility. Sediment is then generally loaded to either trucks or rail cars by derrick cranes or mechanical conveyors for transfer to the final destination, such as a landfill facility. In cases where on-site disposal options are employed, sediment may be directly conveyed from barges or the dredge via pipeline. There will be a new EPA requirement to notify the affected region whether contaminated material is being shipped through an Environmental Justice community (e.g., racial minorities, residents of economically disadvantaged areas) en route to the final disposal location.

10.10 SCREENING OF TREATMENT TECHNOLOGIES

This section provides an overview of sediment treatment technologies and screening of treatment technologies for the Lockheed West Site remedy.

10.10.1 Description

Treatment technologies for sediments reduce or eliminate toxicity, mobility, or volume of a chemical of concern by implementing a process that alters, bonds with, isolates, or completely destroys the chemical. Guidance from the EPA encourages tracking and evaluation of treatment technologies, although significant technical limitations do currently exist for many technologies applicable to sediments (EPA, 2005b). A general CERCLA preference for the treatment of contaminated media over containment or disposal is indicated by the NCP and the EPA (EPA, 1988).

The NCP establishes an expectation that EPA will use treatment to address the principal threats posed by a site wherever practicable. In general, principal threat wastes are those source materials considered to be highly toxic or highly mobile that generally cannot be contained in a reliable manner. According to 40 CFR 300.430(a)(iii), EPA expects that treatment will be used

for “principal threat” (i.e., high concentration, toxic, and highly mobile) materials whereas engineering and/or institutional controls may be used for “low-level threat” materials.

For the majority of sediment removed from Superfund sites in the United States, treatment is not conducted prior to disposal, generally because sediment sites often have widespread low-level contamination (EPA, 2005b). However, pretreatment, such as particle size separation for hazardous/nonhazardous waste disposal, is common. Concentrations of COCs at the Lockheed West Site, like most sediment sites, are classified as low-level threat waste, not as a principal threat waste.

10.10.1.1 *In Situ* Treatment Technologies

In situ treatment of sediments refers to chemical, physical, or biological techniques for reducing COC concentrations while leaving the contaminated sediment mass in place. There are numerous technologies for *in situ* treatment of soil and, conceptually, a number of these technologies may be applicable to sediment. Remediation technologies that can be practically applied *in situ* to treat sediments are limited, however, due in part to the challenges posed by working through the water column (e.g., accessibility and control and monitoring of a treatment process) and the saturated and often anaerobic condition of the sediments. Two potentially applicable *in situ* treatment technologies are as follows:

- **Solidification/Stabilization**—Involves the injection/mixing of binding agents, such as portland cement, lime-kiln dust, polymers, and/or proprietary agents, to alter the physical/chemical characteristics of the impacted sediments and render them unavailable for ecological/human exposure.
- **Biological/Chemical Treatment**—Involves the injection/mixing of microorganisms and/or nutrients (chemicals) to enhance the ongoing biodegradation process and reduce the potential ecological/human exposure risks.

There have been no successful full-scale adaptations of these or other *in situ* treatment technologies reported in the literature to address the risk-driver constituents identified for the Lockheed West Site.

10.10.1.2 *Ex Situ* Treatment Technologies

Ex situ treatment refers to the processing of dredged sediments to transform or destroy COCs. *Ex situ* treatment of contaminated sediments is considered as part of the removal by dredging and/or excavation response action. *Ex situ* treatment often involves a combination of processes or treatment to address various contaminant problems, and includes pretreatment, operational treatment, and/or effluent treatment/residual handling. Pretreatment is performed to meet chemical and physical requirements for treatment or disposal and/or to reduce the volume/weight of sediment that requires transport, treatment, or restricted disposal. Dredge material could potentially be treated using the processes described in the following sections.

Biological

Biological treatment involves the addition and mixing of microorganisms or nutrients (chemicals) to enhance ongoing biodegradation processes and reduce the potential ecological or human exposure risks. Although light-weight polycyclic aromatic hydrocarbons and some semivolatile organic compounds are amenable to biological treatment, metals, PCBs, dioxins, and tributyltin are not well-suited to biological treatment techniques.

Physical/Chemical

Physical treatment technologies, such as solidification/stabilization processes, immobilize contaminants in dredged material by injecting and mixing an immobilization agent into the dredged material. A variety of agents, such as portland cement, pozzolanic materials, polymers, and proprietary agents, have been utilized. Such processes also have the potential to improve the handling characteristics of the dredged material.

Chemical treatment is typically used in conjunction with physical treatment to enhance contaminant removal, immobilization, or degradation. Potentially applicable chemical treatment technologies include the following:

- **Soil Washing**—This is a physical or physical/chemical process that reduces the volume of soil material requiring further treatment or disposal by separating contaminants that adhere to organic matter and fine particles within a sediment matrix. The technique is developed to conventional and advanced soil washing, where advanced soil washing (e.g., Biogenesis™), combines the physical separation aspects of conventional soil

washing with additional treatment such as agitation, or the addition of surfactants, chemical oxidants, or chelating agents to the finer fraction of material.

- **Extraction**—This is a treatment process by which contaminants are extracted from sediments using chemical solvents.

Physical

Physical treatment technologies are processes that change the affected medium through the application of physical forces (separation technologies such as gravity separation or filtration).

Thermal

Thermal treatment technologies use heat as the primary mechanism for removal by volatilization or destruction of chemical compounds in sediments. Thermal process options may be grouped into the categories of pyrolysis, high-pressure oxidation, incineration, thermal desorption (both high and low temperature), and vitrification.

Example thermal treatment technologies are:

- **Incineration**—controlled high-temperature process that uses combustion to destroy contaminants resulting in a reduction in volume and/or toxicity of the contaminated dredge material; and
- **Thermal Desorption**—treatment technology that separates the contaminants from the dredged material matrix at a lower temperature than incineration causing the contaminants to volatilize.

10.10.2 Evaluation

The anticipated effectiveness of *in situ* and *ex situ* treatment technologies for sediments at the Lockheed West Site is low because none of the technologies alone would treat both organic and inorganic sediment contaminants. A combination of technologies would be needed for them to be effective. For example, for organic contaminants, thermal treatment and biological treatment could be considered. However, metals would not be treated thermally or biologically and would have to be treated with soil washing, extraction technologies, or by solidification. In general, the treatment technologies are expected to provide a limited incremental benefit in toxicity reduction, destruction, and immobilization compared to the incremental benefit from removal of contaminants from the system and off-site landfill disposal.

The RETEC (2005b) study included a comprehensive screening of treatment technologies for viability and applicability to the sitewide cleanup in the Lower Duwamish Waterway. Generally, sediment treatment options have been shown to be impracticable with disproportionately higher costs than alternative sediment management strategies that have been implemented or contemplated in the Puget Sound region. Using this screening process, several potentially applicable technologies were identified that were carried forward into the LDW FS (RETEC, 2005b). That FS contained tentative conclusions that there are no viable *in s itu* treatment technologies currently demonstrated for sediment containing mixtures of organic compounds and metals. Accordingly, that FS was focused on *ex si tu* technologies including conventional soil washing, advanced soil washing, solidification, and thermal treatment (AECOM, 2010). Solidification or thermal treatment were not carried forward for further consideration because the solidification does not adequately treat the COCs, solidified sediment would still require transport to a landfill for disposal, and the thermal treatment process is unlikely to achieve the total metal concentration limits for beneficial reuse. Conventional soil washing/particle separation and advanced soil washing were carried forward in developing the remedial alternatives (AECOM, 2010). The LDW FS also reported significant uncertainties with the treatment option such that if soil washing were employed, bench-and pilot-scale testing would be needed to confirm the assumption that sand-size material can be treated to an acceptable level for beneficial reuse. Additional permitting requirements may also limit the reuse of sand. Water quality criteria may also limit the effectiveness of water management or dictate the need for additional water treatment.

As concluded in a recent feasibility evaluation completed for the Slip 4 Early Action Area within the LDW (Integral, 2006), soil-washing and high-temperature thermal desorption have limitations on effectiveness for removing contaminants from fine sediment particles (silts and clays). The Lockheed West Site surface and subsurface sediments contain approximately 35 percent silts and clay, while intertidal sediments have about 1.5 percent fines. This is a key limitation of these technologies because contamination is predominately adsorbed to fine sediment particles (silts and clays). Another limitation is that fixed facilities for high-temperature thermal desorption or soil washing are not available in this region. Siting and permitting of such facilities, especially for a one-time event, would present substantial implementation issues. Further, given that the sediments would likely still contain residual contamination (e.g., metals)

following treatment, the potential for acceptance for reuse is low. Consequently, sediments would likely require disposal at an off-site facility even after treatment.

In situ treatment technology is in the developing stage. Some of the problems that require resolution are negative impacts on the water column by the sediment disturbance during application of the reagents or the amendments; controlling the treatment process to provide uniform results throughout the sediment; effectiveness of the process under saturated, anaerobic conditions at ambient temperatures; and developing methods to treat deeper sediment deposits.

In situ biological/chemical treatment requires delivery or injection and mixing of substrates into the sediment, which poses challenges. In addition, the mechanisms influencing degradation are not well-understood. Until the processes driving degradation are identified, there is no way to know if the mechanisms that biologically break down the contaminants can be controlled or accelerated. The cost for *in situ* biological/chemical treatment would be high because this technology requires more research and understanding before implementation. Even if the mechanisms driving reductive dechlorination were understood, the cost to deliver nutrients or other materials over a large area at depth could be high. No successful adaptations of these and other technologies to full-scale sediment cleanup involving PCBs have been reported in the literature.

Ex situ treatment technologies require sediment removal (i.e., dredging), generally followed by dewatering of the sediment and treatment of both the dewatered sediment and water. This approach requires treatment application in a nearby confined facility where physical, chemical, biological, and thermal processes are used to remove contaminants from the sediment. Solidification is a proven technology that reduces the moisture content of dredged sediments and reduces the leachability of metals. The process consists of the addition of cement, kiln dust, or other absorbent and solidification agent. However, the process does not treat all of the COCs in site sediment and the sediment would still require landfill disposal. There are two solid waste landfills in the region that are licensed to accept sediments that have excess water, or wet sediments. Wet sediment can effectively be transported by closed-container rail with minimal dewatering to control free water during transport; therefore, solidification presents little, if any,

advantage and would create an increased quantity (mass) of material to be handled and disposed of.

Sediments in portions of the Lockheed West Site may be sufficiently coarse-grained to consider soil washing as a potentially viable treatment technique similar to Lower Duwamish Waterway sediments. Other than physical and chemical properties of sediments, economics and implementability of soil washing are based on 1) availability of an upland location for transloading sediment from barges; 2) availability of an upland location for sediment containment, storage, and operation of the soil washing facility; 3) disposal costs for the fines fraction; 4) ability to commit to long-term (and continuous) high-volume sediment throughput; and 5) ability to reuse washed coarse fraction beneficially and at low cost. The end use options of the treated sand fraction could meet the applicable chemical and physical requirements for in-water beneficial reuse; be suitable for upland use as fill with no associated value or disposal cost; be suitable for open-water disposal with a comparatively low disposal cost; or require landfill disposal at significant cost (AECOM, 2010). In the final draft LDW FS, the soil washing treatment option is incorporated into one long-term alternative in which about 1.5 million cubic yards of contaminated sediments would be dredged in 19 years, where half of these sediments would go through soil washing treatment that would produce about 385,000 cubic yards of treated sand for an undetermined end use. The size, extent, and volume of contaminated sediments at the Lockheed West Site sediment remediation project are much lower than those at the LDW. Because the Lockheed West Site remediation project is not expected to produce a large volume of sediment over a long enough period of time to meet the economic and implementability criteria, it is not justified to incorporate the soil washing treatment technique into a remedial alternative for the Site.

Based on the evaluation presented here, the ongoing *ex s itu* treatment evaluation process of LDW sediments, and the conclusions of the Slip 4 engineering evaluation/cost analysis (which did not retain treatment technologies), no treatment technologies are retained for further consideration in the FS. Table 10-9 summarizes the treatment technologies and process options and associated screening decision.

10.11 SCREENING OF DISPOSAL/REUSE TECHNOLOGIES AND PROCESS OPTIONS

This section contains a summary of disposal and reuse technologies and the screening evaluation for the Lockheed West Site cleanup.

10.11.1 Description

Disposal actions are generally combined with removal actions. Dredged material may be disposed of on-site or at an off-site waste disposal facility. In both cases, the final placement of the material must be in a manner that will prevent the contaminated dredge material from returning to the environment. On-site disposal can be executed on land, in a nearshore CDF or in a confined aquatic disposal (CAD) facility. Off-site disposal can be either at an aquatic disposal site or at an approved upland waste disposal facility.

10.11.1.1 On-Site Disposal

This section contains a description of general on-site disposal options.

Upland On-Site Disposal

In most cases, dredged material is characterized as nonhazardous waste. Therefore, on-site disposal of the dredge material is often considered. The design and construction of a landfill facility would be required to meet the requirements of state and federal landfill design criteria. In some cases, on-site disposal is considered in conjunction with sediment treatment. If the treatment can render the dredged material inert or if the dredged material meets the MTCA Method A and Method B Soil Cleanup Levels for unrestricted land use (WAC 173-340-740), on-site disposal may be possible without typical landfill design provisions, such as liners, covers, and seepage recovery systems.

Upland on-site disposal is normally an effective way to meet the RAOs. The technical and administrative feasibility and the cost of on-site disposal greatly depend on site-specific conditions, dredged material contaminant levels, and the future use of the property. Upland on-site disposal requires available land for construction of a containment facility, and such space is not available at the Lockheed West Site.

On-Site Disposal in a Nearshore Confined Disposal Facility

Dredging projects may utilize a nearshore CDF for the disposal of dredged material. The nearshore CDF is an engineered structure constructed in the water directly adjacent to the upland portion of a site for the containment of dredged material. A nearshore CDF consists of berms, cofferdams, or similar structures that enclose a disposal area by isolating the dredged material from adjacent waters during placement. Dredged material is placed behind the berm, initially in the water. As the area behind the berm is filled, uplands are created contiguous with the upland portion of a site. Construction of a CDF can eliminate the need for dewatering or other treatment of the dredged material and can reduce the distance (and cost) of sediment transport for disposal.

The selection and design of the CDF needs to provide for long-term isolation of the sediment. A CDF is frequently used when the future land-use can benefit from the creation of new land and the potential for leaching of sediment contamination is generally low.

Using a CDF is normally an effective way to meet RAOs. The technical and administrative feasibility and the cost of a CDF greatly depend on site-specific characteristics.

On-Site Disposal in a Confined Aquatic Disposal Facility

For some dredging projects, the bathymetric conditions allow the use of a CAD facility for the disposal of the dredged material. Confined aquatic disposal is a form of capping that includes the added provision of some form of lateral containment. The CAD facility is constructed normally in deeper water, where there is natural depression, sometimes further deepened and shaped by dredging, or where subaqueous berms can be constructed. Dredged sediment is transferred to the CAD facility and then capped with clean material.

The selection and design of a CAD facility must provide for long-term isolation of the sediment and associated pore water. Other factors to be considered during site selection and design include distance from dredging site, seabed stability, seismic conditions, currents, and permitting and navigational requirements in the area of the CAD.

Using a CAD facility is normally an effective way to meet RAOs. The technical and administrative feasibility and the cost of a CAD facility greatly depend on site-specific characteristics.

10.11.1.2 Regional Disposal Alternatives

Dredged sediment can be disposed of off site at an aquatic disposal facility or at an upland waste disposal facility. The USACE and EPA select and operate open-water disposal areas where sediment found suitable for unconfined aquatic disposal, normally from navigational dredging projects, can be disposed of. Dredged sediment from contaminated sediment sites typically does not meet the DMMP sediment quality requirements of aquatic disposal. However, a portion of Lockheed West Site dredge material may satisfy these criteria and be acceptable for aquatic disposal at a DMMP site.

In most cases when off-site disposal is considered, approved upland waste disposal facilities are used. To be disposed of at a waste disposal facility, the dredged material must meet the waste acceptance criteria of the specific landfill considered. One of the most important acceptance criteria is the final water content of the material: no free liquid is allowed unless the landfill is designed to accept wet sediments. The leachability potential of the entrained contaminants also forms an important landfill acceptance criterion. The dredged material may require some form of passive or mechanical dewatering or solidification/stabilization to meet the “no free liquid” and other waste acceptance criteria of the specific landfill. In EPA Region 10, there are Subtitle D landfills licensed to take both dewatered and wet sediments.

Standard practice in environmental dredging operations also includes removal of large debris, such as logs, concrete, and boat hulls. Removed debris that meets waste acceptance criteria will be shipped to an upland landfill or utilized for potential recycling and beneficial reuse.

Subtitle D Landfills

There are several off-site Subtitle D solid waste landfills in the region that are licensed to accept sediments not classified as dangerous wastes. Such facilities include the Greater Wenatchee Regional Landfill in Wenatchee, Washington, and the Columbia Ridge Landfill in Arlington, Oregon, both operated by Waste Management, and the Roosevelt Regional Landfill in Klickitat County, Washington, operated by Allied/Rabanco. Solid waste landfills in Washington State are regulated primarily by local health departments under the authority and requirements of the Minimum Functional Standards for Solid Waste Handling (WAC 173-304), the Solid Waste Handling Standards (WAC 173-350), Criteria for Municipal Solid Waste Landfills (WAC 173-

351), and the Resource Conservation and Recovery Act (RCRA; Subtitle D). As identified in WAC 173-304(100), dredge spoils resulting from the dredging of surface waters containing contaminants at concentrations not suitable for open water disposal but that are not dangerous wastes, are not regulated by Section 404 of the federal Clean Water Act. Dredged spoils are defined as problem wastes, which is a category of waste that is accepted at solid waste landfills. Dangerous wastes in Washington State are defined in WAC 173-303, Dangerous Waste Regulations. Dangerous waste can be characterized according to the maximum allowable concentration of contaminants for the toxicity characteristics presented on page 90 of WAC 173-303. Listed criteria include arsenic at 5 milligrams per liter, lead at 5 milligrams per liter, and mercury at 0.2 milligram per liter. Other COC risk drivers at the Lockheed West Site are not included. In general, sediment that is not eligible for open-water disposal and will pass the TCLP test, as defined in WAC 173-303, can be disposed of in a solid waste landfill. Based on available Site characterization data and sediment characteristics, it is anticipated that, if excavation were to occur, all sediment material removed from the Lockheed West Site would likely qualify for Subtitle D disposal. Material found to be inappropriate for a Subtitle D landfill could be disposed of at an appropriate facility as described below.

Dewatered Sediments

Requirements regarding disposal of sediments at most Subtitle D landfills (see following section) include provisions that the sediment be dewatered so that it will pass the paint filter test for free water. Of the landfills discussed above, only the Greater Wenatchee Regional Landfill has this requirement. Dewatering of the sediments is required for both transport and disposal of the dredged material; therefore, a dewatering facility needs to be present at the point where the wet sediments are offloaded from the haul barge to the shore.

Wet Sediments

There are two solid waste landfills in the region that are licensed to accept sediments that have excess water, or wet sediments: the Roosevelt Regional Landfill operated by Allied/Rabanco and the Columbia Ridge Landfill operated by Waste Management. Both have received exemptions from state, federal, and county requirements to accept sediments with free water. The amount of free water that is acceptable over a certain time period is written into the operating permit of the landfills. The free water is used to enhance the moisture condition of the landfill, providing

greater compaction ratios and increased methane production in the landfill. Transport of the wet sediment is required to be by closed-container rail only to prevent water spillage, with local trucking permitted only on the landfill property.

Handling wet sediments generally requires a transfer facility. Wet sediment may be directly transferred from the haul barge to a lined rail car. Alternatively, wet sediment may be transferred to an interim transfer cell, possibly on-site, for passive dewatering. Then, sediment can be loaded into lined roll-off containers that are subsequently transferred to rail cars. Previously, Allied/Rabanco had an active sediment offloading facility at Terminal 25 along the East Waterway at the mouth of the Duwamish River but that lease expired in 2005. Both Allied/Rabanco and Waste Management have indicated that their intention is to develop a new transfer facility (RETEC, 2005b). The potential availability of such a facility or siting a new facility will be evaluated during design.

Barge offloading/rail loading facilities can also be constructed for a specific project if an existing facility is not available or not economical.

Subtitle C and Toxic Substances Control Act Landfills

There are several possible waste designations that have special landfilling requirements: Washington State Dangerous Waste, Toxics Substances Control Act remediation waste, and RCRA-listed or characteristic waste. Sediments containing PCBs at concentrations greater than 50 parts per million are considered hazardous wastes under the Toxic Substances Control Act, and are required to be either disposed of in an approved Toxic Substances Control Act landfill or destroyed. However, if EPA approves a risk-based option (40 CFR 761.61[c]) for PCB remediation waste, solid waste landfills or RCRA Subtitle C hazardous waste landfills may also be used, if consistent with the disposal facility permit and state regulations. Sediments that meet the definition of RCRA hazardous waste must meet the RCRA land ban requirements prior to disposal, which may require treatment of the sediment prior to disposal. Chemical Waste Management operates a Subtitle C and Toxic Substances Control Act-approved landfill in Arlington, Oregon, that is adjacent to its Subtitle D Columbia Ridge Facility. Unlike the Subtitle D facility, the sediments must pass the paint filter liquids test to enter the Toxic Substances Control Act–permitted facility.

Table 10-10 provides a summary of the discussion on regional disposal facilities and waste acceptance criteria.

10.11.1.3 Post-Treatment Management Alternatives

Contaminated sediments generated as a result of removal actions may be beneficially reused without disposal restrictions, provided they are treated as described below.

In-Water Beneficial Use

Sediments treated to below DMMP guidelines may be beneficially reused for in-water applications such as capping, habitat creation, or residual management. Any potential in-water beneficial use application would be required to meet associated material specifications to ensure an appropriate match between physical, chemical, and biological material properties and functionality in the aquatic environment.

Upland Beneficial Use

Treated sediment must meet the MTCA Method A Soil Cleanup Levels for unrestricted land use (WAC 173-340-740) to be beneficially reused in upland areas in Washington State without restrictions.

10.11.2 Evaluation

This section presents the evaluation of disposal/reuse options.

10.11.2.1 Effectiveness

Off-site disposal at permitted landfills is considered effective, although it may not satisfy the CERCLA preference for contaminant mass reduction. On-site disposal is potentially effective but has other limitations as described below. The effectiveness of a disposal technology depends upon the residual concentrations of COCs in the dredged or treated sediments. Subtitle D landfills are suitable for all contaminants that are not designated as state dangerous waste, RCRA hazardous waste, or Toxic Substances Control Act remediation waste.

Beneficial reuse is defined as the reuse of dredged material, or some portion of it, as a resource instead of disposing of it as a solid waste. It involves using the dredged material in a productive manner, such as habitat creation or restoration, landscaping, soil/material enhancement,

construction fill, or land reclamation. Dredged material may have some value if applied for beneficial reuse. Beneficial reuse has limited effectiveness due to limitations of treatment technologies. Treated materials must meet MTCA or DMMP guidelines for reuse. Treatment and permitting issues aside, beneficial reuse presents an opportunity to reduce the quantity of imported backfill for use as cap material if acceptable for use on-site. Sediment for reuse in upland areas must meet the MTCA Method A Soil Cleanup Levels for unrestricted land use (WAC 173-340-740) to be beneficially reused without restrictions. The DMMP guidelines would determine suitability of treated material for beneficial use at in-water locations other than at the Lockheed West Site (e.g., as capping material or habitat enhancements). Several factors including physical and chemical characteristics of the material, regulatory criteria and approvals, and environmental concerns are considered in the DMMP. In all cases, federal, state, and local laws incorporate provisions such that any beneficial use of treated dredged sediments must not result in an unacceptable risk to human health or the environment, and must not be used in a manner that results in the degradation of application-site conditions in soil, surface water, groundwater, and air. Beneficial reuse of dredged material will be evaluated during the remedial design phase.

10.11.2.2 Implementability

Off-site disposal of dredged sediments at permitted landfills is routinely implemented. On-site disposal is more difficult to implement given the time required to fully investigate, design, and site a facility. Implementability of on-site disposal may be further reduced by issues regarding availability of suitable property due to ownership and land use restrictions. As the evaluation process proceeds during the design, more details regarding future land use, property ownership and mitigation, and ESA requirements will be gathered. However, given the current uncertainty regarding the existing and future uses and property ownership in the vicinity of the Site, implementation of this on-site disposal option is considered unlikely but may be further explored during the design.

The Port owns the intertidal sediments in the area where a CDF would most likely be sited. Nearshore CDFs may reduce available intertidal habitat, triggering ESA concerns, and may complicate project approval. An ESA consultation with NOAA and the U.S. Fish and Wildlife Service would be conducted during remedial design. However, these concerns can be offset

through mitigation measures by creating new, higher quality, intertidal habitat elsewhere on the site. A CDF may integrate well into future land-use options (e.g., nearshore dock facilities, habitat improvement) and would be sited and designed as a Superfund disposal facility. Examples of CDFs for contaminated sediments implemented in Washington State are the Milwaukee and St. Paul Waterways in Tacoma, the Eagle Harbor East OU in Winslow, Terminal 90-91 in Elliott Bay, Pier 1-3 in Everett, and the Blair Waterway Slip 1 (RETEC, 2005b).

Substantive compliance with permit requirements, land ownership, and bathymetric constraints poses challenges for use of a CAD facility. There would likely be joint Port and DNR property ownership/stewardship of the area for a potential CAD site. The area also includes tribal U&A areas; any CAD facility would be required to avoid conflicting with or restricting tribal treaty fishing rights or other treaty protected rights such as anchorage of tribal fishing vessels or access to aquatic resources. A CAD facility must be designed, built, and managed for reliable placement and monitoring and to prevent potential bioturbation, advection of contaminants into the clean confined aquatic disposal cover by groundwater, and scour by propeller wash or other hydraulic forces. Unlike a nearshore CDF, a CAD facility is not as easily integrated into future land-use options because it has no potential use other than disposal function whereas a CDF can be utilized for industrial and habitat improvement purposes. Similar to a capping operation, construction of CAD facility would require institutional controls such as deed or use restrictions, potential waterway use restrictions for activities that could disturb a cap, and a commitment to a long-term operation and maintenance plan. While a natural depression area is typically utilized for a CAD facility, further excavation may be required to keep existing depths. Design criteria of both confined disposal and confined aquatic disposal facilities should include preservation of tribal fishing and clamming rights.

Beneficial reuse of dredged material is more difficult to implement given treatment limitations and permitting requirements.

Regarding implementability of a nearshore CDF or CAD facility at the Site, EPA, DNR, and the Muckleshoot Indian Tribe representatives have recently discussed and explored the issues associated with siting such disposal facilities. This meeting led to the conclusion that neither of these disposal options is feasible at Lockheed West Site. The EPA will provide meeting notes

from this discussion for the Administrative Record to memorialize that this option was considered and the reasons for not exploring it any further (EPA, 2010c).

10.11.2.3 Costs

The cost assessment of the disposal options is based on the relative cost of a disposal process option compared to others. Off-site disposal at permitted landfills may have moderate to high associated costs, depending on waste characterization. Development of an on-site disposal option would require significant expenditures for evaluation, design, construction, and land acquisition. For an on-site facility to be cost effective, development costs generally need to be spread over disposal volumes exceeding 100,000 cubic yards (Integral, 2006). A nearshore CDF could be more cost-effective if implemented as part of a future development plan that could include nearshore dock facility or habitat improvement. The future development plans would likely have to be permitted using the process established through the USACE outside of the Superfund program. Costs associated with beneficial reuse of dredged material may be moderate to high depending on the treatment technique, reuse requirements, and effectiveness/usability of dredged materials for the intended purpose.

10.11.3 Screening Summary

Off-site upland disposal technologies (permitted landfills) are retained for evaluation as part of remedial alternatives in the FS. Nearshore CDFs and CAD facilities are retained as potentially applicable technologies for design but not carried forward for detailed analysis in the FS. Off-site disposal at a permitted solid waste disposal facility is retained to be incorporated into the assembly of alternatives. Other off-site disposal options and beneficial reuse options are retained for design but not carried forward for detailed analysis in the FS. Table 10-11 summarizes the results of the screening process for disposal and reuse technologies and process options.

10.12 SUMMARY OF RETAINED TECHNOLOGIES

Potentially applicable remedial technologies and process options to be considered in the development and evaluation of sitewide remedial alternatives for the Lockheed West FS were identified, screened, and discussed in this section. This screening was based on Site-specific conditions and the major risk drivers for Lockheed West Site sediments and each technology was evaluated for effectiveness, implementability, and relative cost.

Based on the results presented in Sections 10.4 through 10.10, Table 10-12 presents a list of retained remedial technologies. Table 10-13 provides a summary of ancillary technologies potentially appropriate for Lockheed West Site sediment remediation.

Table 10-1.
Identification of General Response Actions, Technology Types, and Process Options Potentially Appropriate for Lockheed West Site Sediment Remediation (Page 1 of 2)

General Response Action	Technology Type	Process Option	Description of Process Option
Institutional Controls	Physical, Engineering and/or Legislative Restrictions	Educational Programs/Warning Signs/Consumption Advisories	See Section 10.4
		Shoreline Access and Property Use Restrictions	
		Waterway Use Restrictions	
Natural Recovery	Monitored Natural Recovery	Recovery Modeling and Long-Term Monitoring	See Section 10.5
	Enhanced Natural Recovery	Thin-Layer Placement	
		Thin-Layer Placement with Carbon Amendments	
Containment	*In Situ* Capping	Conventional Sediment Capping	See Section 10.6
		Composite Capping	
		Reactive Capping	
Removal	Dredging	Mechanical Dredging	See Section 10.7
		Hydraulic Dredging	
		Specialty Dredging	
	Dry Excavation	Excavator	
In Situ Treatment	Biological	Slurry Biodegradation	See Section 10.9 [1/]
		Aerobic Biodegradation	
		Anaerobic Biodegradation	
		Imbiber Beads	
	Chemical	Slurry Oxidation	
		Aqua MecTool™ Oxidation	
	Physical-Extractive Processes	Oxidation	
		Sediment Flushing	
	Physical - Immobilization	Aqua MecTool™ Stabilization	
		Electro-chemical Oxidation	
		Vitrification	
		Granulated Activated Carbon Addition	
		Ground Freezing	
Ex Situ Treatment	Biological	Enhanced Bioremediation	See Section 10.9 [1/]
		Slurry-phase Biological Treatment	
		Fungal Biodegradation	
		Landfarming/Composting	
		Biopiles	

Table 10-1.
Identification of General Response Actions, Technology Types, and Process Options Potentially Appropriate for Lockheed West Site Sediment Remediation (Page 2 of 2)

General Response Action	Technology Type	Process Option	Description of Process Option
Ex Situ Treatment (cont'd)	Physical/Chemical	Acid Extraction	
		Solvent Extraction	
		Slurry Oxidation	
		Reduction/Oxidation	
		Dehalogenation	
		Sediment Washing	
		Radiolytic Detoxification	
	Physical	Separation	
		Solar Detoxification	
		Solidification	
	Thermal	Incineration	
		High-temperature Thermal Desorption	
		Low-temperature Thermal Desorption	
		Pyrolysis	
		Thermal Desorption	
		Vitrification	
		High-pressure Oxidation	
Disposal/Reuse	On-Site Disposal of Dredge Material	Confined Disposal Facility	See Section 10.10
		Confined Aquatic Disposal	
	Off-Site Disposal of Dredge Material	Open Water Disposal	
		Off-Site Disposal at a Permitted Solid Waste Disposal Facility	
		Off-Site Disposal at a Landfill Permitted to Accept Washington State only Dangerous Waste	
		Off-Site Disposal at a Hazardous Waste Landfill	
		Off-Site Disposal at a TSCA Landfill	
	Beneficial Reuse	In-Water Beneficial Reuse	
		Beneficial Reuse as Fill	

Notes:
1/ For a detailed discussion of *in situ* treatment technologies and process options, see the Lower Duwamish Waterway Candidate Technical Memorandum (RETEC, 2005b).
TSCA = Toxics Substances Control Act.

Table 10-2.
Identification of Ancillary Technologies and Process Options Potentially Appropriate for Lockheed West Site Sediment Remediation

General Response Action	Technology Type	Process Option	Description of Process Option
Ancillary Technologies	Water Treatment	Dewatering	See Section 10.8
		Wastewater Treatment	
	Material Transport	Pipeline Transport	
		Vehicle Transport	
		Rail Transport	
		Water Transport	

Table 10-3.
Detected Concentrations of Major Risk Drivers at the Lockheed West Site

Risk Driver	Basis[1/]	Detected Subtidal and Intertidal Surface Concentrations		Detected Subsurface Concentrations	
		Min	Max	Min	Max
HPAHs (as a surrogate for cPAHs)	mg/kg dw	0.0288	70.74	0.0018	163.9
	mg/kg OC	22	2190	0.34	13828
Arsenic	mg/kg dw	4.56	330	1.11	374
Lead	mg/kg dw	15.9	1420	1.76	2200
Copper	mg/kg dw	28.2	1900	6.7	2620
Mercury	mg/kg dw	0.021	2.94	0.0005	17.1
TBT	mg/kg dw	0.00081	4.5	0.00021	9.1
	mg/kg OC	0.5	392	0.02	1900
Total PCBs	mg/kg dw	0.0042	3	0.0041	9.62
	mg/kg OC	1.6	201	0.5	689
Dioxin/furans[2/]	—	—	—	—	—

Notes:
Complete data set is provided in Section 4 and Appendix A. Data are also summarized in the final risk assessments (Tetra Tech and Pascoe, 2009a,b).
1/ The dry weight results are for all of the remedial investigation samples collected. The organic carbon normalized results are for samples with organic carbon content greater than 0.5 percent. For parameters with both dry weight and organic carbon normalized data the specific samples for the minimum and maximum concentrations presented may be different.
2/ Data for dioxins and furans were not collected at the site. However, they were identified as risk-driver chemicals in the human health risk assessment based on their assumed likely presence in the site sediment and seafood from the site as they are documented to be in the upstream Lower Duwamish Waterway and represent a chemical of concern at the nearby Pacific Sound Resources Marine Sediment Unit.
cPAH = carcinogenic polycyclic aromatic hydrocarbon
HPAH = heavy-weight polycyclic aromatic hydrocarbon
mg/kg dw = milligram per kilogram dry weight
mg/kg OC = milligram per kilogram organic carbon
PCBs = polychlorinated biphenyls
TBT = tributyltin

Table 10-4.
Screening of Institutional Control Remedial Technology Types and Process Options

General Response Action	Technology Type	Process Option	Evaluation Based on Effectiveness	Evaluation Based on Implementability	Evaluation Based on Relative Cost	Applicable to Lockheed West	Screening Decision
Institutional Controls	Governmental Controls	Monitoring and Notification of Waterway Users	Moderate to High. Effective when used in conjunction with active remedies.	Moderate to high	Low	Yes	Retained
	Proprietary Controls	Deed Restriction	High	Moderate to high	Low	Yes	Retained
	Enforcement and Permit Tools	Permits, Consent Decrees	High	Moderate to high	Low	Yes	Retained
	Informational Devices	Education and Public Outreach	Moderate to High. Effective when used in conjunction with active remedies	Moderate to high	Low	Yes	Retained
		Seafood Consumption Advisories		Moderate	Low	Yes	Retained
		Site Registry	High	Moderate to high	Low	Yes	Retained

Table 10-5.

Screening of Monitored Natural Recovery/Enhanced Natural Recovery Remedial Technology Types and Process Options

General Response Action	Technology Type	Process Option	Evaluation Based on Effectiveness	Evaluation Based on Implementability	Evaluation Based on Relative Cost	Applicable to Lockheed West	Screening Decision
Monitored Natural Recovery	Physical Transport, Chemical and Biological Degradation, Physical-Burial Processes	Biodegradation, Sedimentation, Bioturbation	Low	High	Low	Unknown, data not collected to incorporate into FS alternatives	Retained for design, not carried forward for detailed analysis in the FS
Enhanced Natural Recovery	Enhanced Physical Burial	Thin-Layer Placement	Moderate	Moderate to High	Low to Moderate	Yes, but not as the sole component of a remedy	Retained

Table 10-6.

Screening of Containment Technology Types and Process Options

General Response Action	Technology Type	Process Option	Evaluation Based on Effectiveness	Evaluation Based on Implementability	Evaluation Based on Relative Cost	Applicable to Lockheed West	Screening Decision
Containment	Capping	Conventional Sand/Sediment Cap	High	Moderate to High	Low	Yes	Retained
		Composite Cap	High	Moderate to High	Moderate	Yes	Retained for design, not carried forward for detailed analysis in the FS
		Reactive Cap	High	Moderate	Moderate to high	Yes	Retained for design, not carried forward for detailed analysis in the FS

Table 10-7.
Screening of Removal Technology Types and Process Options

General Response Action	Technology Type	Process Option	Evaluation Based on Effectiveness	Evaluation Based on Implementability	Evaluation Based on Relative Cost	Applicable to Lockheed West	Screening Decision
Removal	Dredging	Mechanical Dredging	Moderate to High	Moderate	Moderate to high	Yes	Retained
		Hydraulic Dredging	Moderate to High	Moderate to High	Moderate to high	Yes	Retained for design, not carried forward for detailed analysis in the FS
		Specialty Dredging	Moderate to High	Moderate	High	Yes	Retained for design, not carried forward for detailed analysis in the FS
	Excavation	Excavation	Moderate to High	Moderate	Moderate	Yes for shoreline areas of the site	Retained

Table 10-8.
Screening of Ancillary Technology Types and Process Options

Technology Type	Process Option	General Suitability and Considerations	Screening Decision
Passive Dewatering	On-barge	Moderate. May not achieve water quality discharge standards.	Retained
	Bermed Stockpile	Moderate. Requires upland space.	Retained
	Pond or Lagoon	Moderate. Requires upland space.	Not Retained
	Solidification	Moderate. Increases solids density (added mass).	Retained
	Geotextile Bags	Moderate.	Retained
Mechanical Dewatering	Centrifugation	Moderate. Requires upland space for processing facilities.	Retained
	Belt Press	Moderate. Requires upland space for processing facilities.	Retained
	Hydrocyclone	Moderate. Requires upland space for processing facilities.	Retained
	Filter Press	Moderate. Requires upland space for processing facilities.	Retained
Transportation	Pipeline Transport	Moderate. Best suited for hydraulic dredge slurry, requires upland processing facilities.	Retained
	Vehicle Transport	High. Requires transferring facilities.	Retained
	Rail Transport	High. Can transport wet sediment in lined cars. Requires rail spur and transferring facilities.[1/]	Retained
	Water Transport	Moderate. Requires transferring facilities.	Retained

1/ A rail transfer facility was available in the past within the Lower Duwamish Waterway corridor. Currently it is not active. Possibility of renovating/reactivating such line would be evaluated during design.

Table 10-9.
Screening of Treatment Technologies and Process Options

General Response Action	Technology Type	Process Option	Screening Decision
In Situ Treatment	Biological	Slurry Biodegradation	Not Retained. For detailed discussion of *in situ* treatment technologies and process, see the Lower Duwamish Waterway Candidate Technical Memorandum (RETEC 2005b).
		Aerobic Biodegradation	
		Anaerobic Biodegradation	
		Imbiber Beads	
	Chemical	Slurry Oxidation	
		Aqua MecTool™ Oxidation	
	Physical - Extractive Processes	Oxidation	
		Sediment Flushing	
	Physical - Immobilization	Aqua MecTool™ Stabilization	
		Electro-chemical Oxidation	
		Vitrification	
		Granulated Activated Carbon Addition	
		Ground Freezing	
Ex Situ Treatment	Biological	Enhanced Bioremediation	Not Retained. For detailed discussion of *ex situ* treatment technologies and process, see the Lower Duwamish Waterway Candidate Technical Memorandum (RETEC 2005b).
		Slurry-phase Biological Treatment	
		Fungal Biodegradation	
		Landfarming/Composting	
		Biopiles	
	Physical/Chemical	Acid Extraction	
		Solvent Extraction	
		Slurry Oxidation	
		Reduction/Oxidation	
		Dehalogenation	
		Sediment Washing	
		Radiolytic Detoxification	
	Physical	Separation	
		Solar Detoxification	
		Solidification	
	Thermal	Incineration	
		High-temperature Thermal Desorption	
		Low-temperature Thermal Desorption	
		Pyrolysis	
		Thermal Desorption	
		Vitrification	
		High-pressure Oxidation	

Table 10-10.
Regional Disposal Facilities

Landfills		Waste Groups Accepted	Dredge Spoil Acceptance Criteria
Subtitle D	Greater Wenatchee Regional Landfill (Wenatchee, WA)	Nonhazardous municipal and solid waste (RCRA)	Dewatered sediments (pass paint filter liquids test)
	Columbia Ridge Landfill (Arlington, OR)		Wet sediments
	Roosevelt Regional Landfill (Roosevelt, WA)		Wet sediments
Subtitle C	Chemical Waste Management Hazardous Waste Landfill (Arlington, OR)	RCRA listed waste, TSCA waste (acidic/corrosives, metals, solvents, PCBs, halogenated organics)	Sediments containing PCBs greater than 50 parts per million or TCLP failure, but passing the paint filter liquids test.

Notes:
PCB = polychlorinated biphenyls
RCRA = Resource Conservation and Recovery Act
TCLP = Toxicity Characteristic Leaching Procedure
TSCA = Toxic Substance Control Act

Table 10-11.
Screening of Disposal/Reuse Technology Types and Process Options

General Response Action	Technology Type	Process Option	Evaluation Based on Effectiveness	Evaluation Based on Implementability	Evaluation Based on Relative Cost	Applicable to Lockheed West	Screening Decision
Disposal	On-Site Disposal of Dredge Material	Confined Disposal Facility	High	Moderate	Moderate to High	Yes	Retained for design, not carried forward for detailed analysis in the Feasibility Study
		Confined Aquatic Disposal Facility	High	Low	Moderate to High	Yes	
	Off-site Disposal	Open Water Disposal	High	Low; subject to meeting Dredged Material Management Plan disposal criteria	Low	Yes	Retained for design, not carried forward for detailed analysis in the Feasibility Study
		Off-Site Disposal at a Permitted Solid Waste Disposal Facility	High	High	Moderate	Yes	Retained
		Off-Site Disposal at a Landfill Permitted to Accept Washington State only Dangerous Waste	High	High	Moderate to High	Yes	Retained for design, not carried forward for detailed analysis in the Feasibility Study
		Off-Site Disposal at a Hazardous Waste Landfill	High	High	Moderate to High	Yes	
		Off-Site Disposal at a Toxic Substances Control Act Landfill	High	High	High	Yes	
Reuse	On/Off-site	In-Water Beneficial Reuse	Moderate	Low	High	Yes	Retained for design, not carried forward for detailed analysis in the Feasibility Study
		Beneficial Reuse as Fill	Moderate	Low	High	Yes	

Table 10-12.
Results of Screening for Remedial Technology and Process Options Potentially Appropriate for Lockheed West Site Sediment Remediation

General Response Action	Technology Type	Process Option	Screening Decision
Institutional Controls	Governmental Controls	Monitoring and Notification of Waterway Users	Retained
	Proprietary Controls	Deed Restriction	Retained
	Enforcement and Permit Tools	Permits, Consent Decrees	Retained
	Informational Devices	Education and Public Outreach, Seafood Consumption Advisories, Site Registry	Retained
Monitored Natural Recovery	Physical Transport, Chemical and Biological Degradation, Physical-Burial Processes	Biodegradation, Sedimentation, Bioturbation	Retained for design, not carried forward for detailed analysis in the Feasibility Study (FS)
Enhanced Natural Recovery	Enhanced Physical Burial	Thin-Layer Placement	Retained
Containment	*In Situ* Capping	Conventional Capping	Retained
		Composite Capping	Retained for design, not carried forward for detailed analysis in the FS
		Reactive Capping	
Removal	Dredging	Mechanical Dredging	Retained
		Hydraulic Dredging	Retained for design, not carried forward for detailed analysis in the FS
		Specialty Dredging	
	Excavation	Excavator	Retained
Disposal/Reuse	On-Site Disposal of Dredge Material	Confined Disposal Facility	Retained for design, not carried forward for detailed analysis in the FS
		Confined Aquatic Disposal Facility	
	Off-Site Disposal of Dredge Material	Off-Site Disposal at a Permitted Solid Waste Disposal Facility	Retained
		Off-Site Disposal at a Landfill Permitted to Accept Washington State only Dangerous Waste	Retained for design, not carried forward for detailed analysis in the FS
		Off-Site Disposal at a Hazardous Waste Landfill	
		Off-Site Disposal at a Toxic Substances Control Act Landfill	
	Beneficial Reuse	In-Water Beneficial Reuse	Retained for design, not carried forward for detailed analysis in the FS

Table 10-13.
Summary of Ancillary Technologies Potentially Appropriate for Lockheed West Site Sediment Remediation

Technology Type	Process Option	Screening Decision
Passive Dewatering	On-barge	Retained
	Bermed Stockpile	Retained.
	Geotubes	Retained for design, not carried forward for detailed analysis in the Feasibility Study
Material Transport	Vehicle Transport	Retained
	Rail Transport	Retained
	Water Transport	Retained

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TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure 10-1
Current Management and Ownership

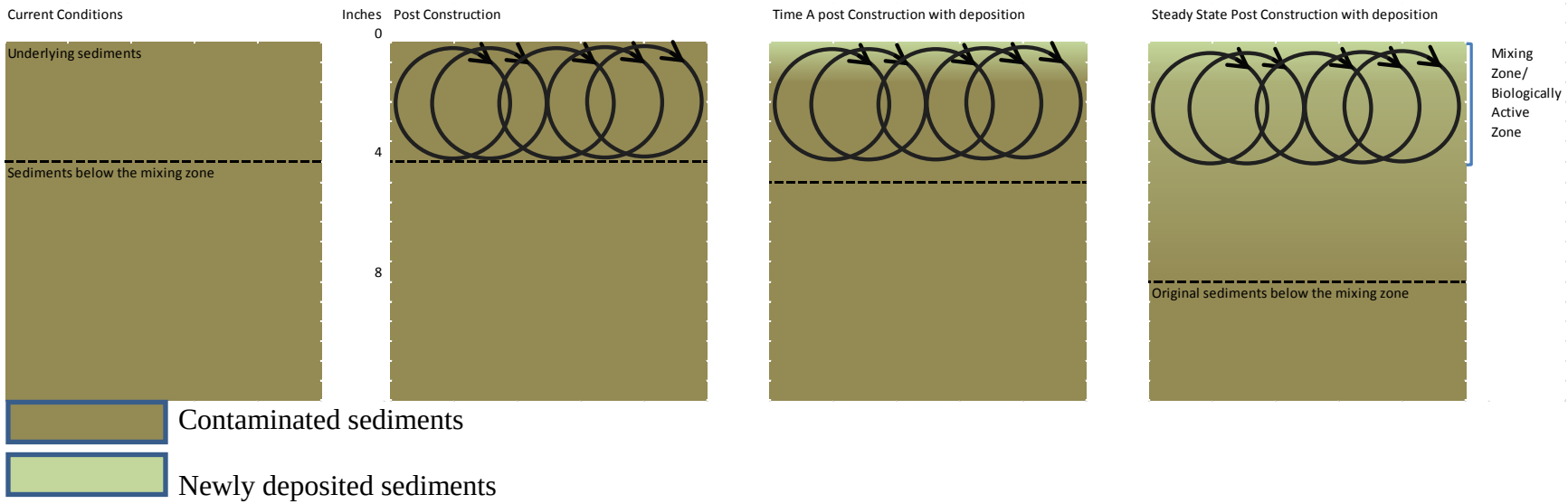

Figure 10-2. Monitored Natural Recovery – Burial and Mixing of Contaminated Sediments with Newly Deposited Cleaner Sediment

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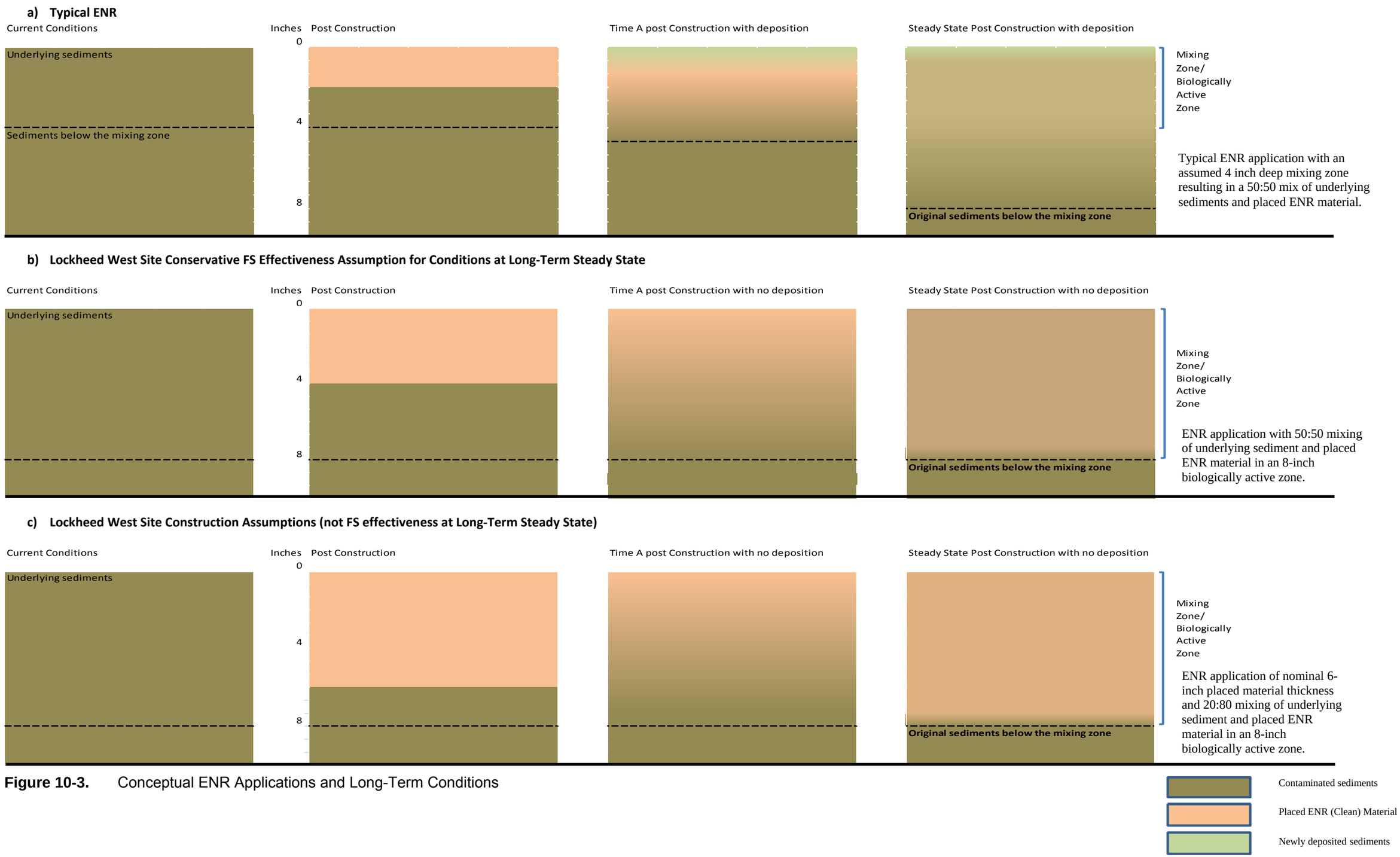


Figure 10-3. Conceptual ENR Applications and Long-Term Conditions

SECTION 11
Development of Remedial Alternatives

This section presents the rationale, assembly, and description of the remedial alternatives for cleanup of the Lockheed West Site contaminated sediments. The alternatives are assembled in a manner consistent with CERCLA guidance (EPA, 1988). The set of alternatives developed herein represents combinations of remedial technologies and process options that are implementable and feasible. Further, the alternatives (with the exception of Alternative 1, No Action) address the remedial action areas and RAOs, while providing variation in the degree to which active removal measures are applied to the site as a whole.

The RAO narratives presented in Section 9.3.1 outline the remedial objectives based on achieving a reduction in risks at the Site. These reductions can be achieved through a variety of active remedial actions including capping, dredging, and ENR. The RAOs also have PRGs associated with them based on the exposure pathways and receptors along with ARARs (see Section 9.4). These PRGs are the sediment concentrations that would eliminate risks or achieve conditions that have been determined to represent natural background levels for the Site. It has been shown that the Elliott Bay region has sediment concentrations that are above natural background conditions for several of the Site risk-driver COCs including PCBs and cPAHs. It is therefore likely that any remedial action taken that achieves those PRGs based on natural background will, in the long term, reach equilibrium conditions that are higher than what the remedy achieved at the end of construction.

One aspect of the proposed remedial actions is that all would produce a clean surface over the areas remediated at the end of construction. This surface would be the result of the placement of clean material for the capping, ENR layer, or residuals management/backfill for dredging. This surface at the end of construction will range in thickness from approximately 6 inches (15 centimeters) to 3 or more feet. Over the long term, the surface and near surface sediments

will reach an equilibrium through mixing and the deposition of new sediment over the post-construction surface. The long-term concentrations for COCs at the Site will be in the range between the natural background levels and the concentrations found in the Elliott Bay region which, for the purposes of the FS, can be represented by the Urban values presented in Section 9.4.1.5.

Through the use of different potential cleanup levels and types of remedial technologies, the remedial alternatives present a range in the spatial extent of active remediation (i.e., areas of potential action), remedial technologies, and costs. For this FS, active remediation refers to capping, dredging, ENR, or some combination of the three (refer to Section 10). Passive remediation refers to sitewide monitoring, institutional controls, or a combination of the two. This range of characteristics for the alternatives allows for a detailed evaluation and comparative analysis of the remedial alternatives (provided in Sections 12 and 13). The process used to develop the remedial alternatives is outlined in the following sections:

- Section 11.1, *Potential Remediation Action Areas and Remedial Action Levels*, includes a discussion of the areas of potential action where there are elevated contaminant concentrations and higher levels of risk. Remedial Action Levels are used in the remedial alternatives to address the risks present and to determine the application of the appropriate remedial technology, such as capping, dredging, and ENR.
- Section 11.2, *Assembly of Remedial Alternatives,* includes a general description of each remedial alternative.
- Section 11.3, *Common Remedy Elements*, contains a description of elements applicable to all remedial alternatives and common engineering assumptions and considerations including site preparation, staging, transloading, disposal, and additional details on the application of remedial technologies and process options.
- Section 11.4, *Detailed Description of Remedial Alternatives*, includes a presentation of the detailed elements of each remedial alternative, including the actively remediated area, volumes of dredged sediment, and common remedy elements.

Final sediment remedial goals have not yet been established for the Lockheed West Site, as they will be established by EPA in the ROD. It is anticipated that remedial goals will be derived from a combination of risk-based threshold concentrations, applicable or relevant and appropriate requirements, and an evaluation of background concentrations of COCs as presented in

Section 9.4. The basis for development of remedial alternatives is to satisfy the four RAOs developed for the Lockheed West Site as presented in Section 9.3. The following section describes how the uncertainties with specific cleanup goals are addressed in the FS.

Late in the review process and following EPA comments on the draft RI/FS document, EPA requested consideration of several variations to the alternatives described and developed in this section. In response to EPA's request, a technical memorandum addressing the variations was prepared and is included as Appendix I to this document.

11.1 POTENTIAL REMEDIATION ACTION AREAS AND REMEDIAL ACTION LEVELS

This section defines the areas of potential action (AOPAs) where there are elevated contaminant concentrations and higher levels of risk. The section also presents the remedial action levels (RALs) used in the remedial alternatives to address the risks present and to determine the application of the appropriate remedial technology (e.g., capping, dredging, and ENR). The AOPAs and the RALs are used in the assembly of the remedial alternatives for the Lockheed West Site.

The AOPAs are the areas of the site where the risk-driver sediment contaminant concentrations are elevated relative to a set of threshold concentrations and potentially require some type of remedial action. The AOPAs are based upon the extent of potential contamination for the risk-driver contaminants as shown in Section 4 and in the *Nature and Extent Summary Memo*. The application of one or more remedial technologies within these areas is considered in developing the alternatives. The boundaries of AOPAs may need to be refined during remedial design and remedial implementation.

The RALs are chemical-specific sediment concentrations that trigger an active remediation. In addition, the RALs are used in this FS to define the areas for the application of different remedial technologies within the AOPAs.

11.1.1 Areas of Potential Action

The AOPAs are defined by comparison of concentrations of risk-driver contaminants in the top one foot of sediment with a threshold level (i.e., SQS, Urban, and study area boundary). The

AOPA boundaries may be modified by physical constraints or boundaries. The AOPA footprints are interpolated using a 3-D visualization model based on the site data as described in Section 4.

The threshold levels used to develop the AOPA footprints for the risk-driver contaminants include the following:

- **SQS**—The SQS footprint is the extent of surface sediment in the subtidal area where the concentrations for the risk-driver contaminants are above the SQS levels of the Sediment Management Standards. The SQS footprint, shown in Figure 11-1, has an area of about 18 acres. This area represents the sediment presenting a risk to benthic organisms and also some level of risk to other receptors. The sediments within this area will require some type of remedial action to achieve the PRGs for RAOs 2, 3, and 4. Remedial actions implemented within this area will also address RAO 1 and achieve the PRGs to some extent; however, they will generally not completely achieve PRGs associated with RAO 1 because areas of the Site outside of the SQS footprint, characterized by concentrations at levels comparable to the Elliott Bay Urban levels but above the natural background based PRGs, would have no action taken in them.
- **Urban**—The Urban footprint is the extent of surface sediment in the subtidal area where the concentrations for the risk-driver contaminants are above the 95 UCL of the Urban bay sampling locations from Elliott Bay (Ecology, 2009a). Section 9 includes a complete definition and describes use of these Elliott Bay data. The implementation of remedial actions within this area will achieve PRGs associated with RAOs 2, 3, and 4 and will also address RAO 1 and achieve PRGs to some extent; however, they will generally not completely achieve PRGs associated with RAO 1 because areas of the Site outside of the Urban footprint where no action would be taken will have concentrations at or below the Elliot Bay Urban levels but above the natural background based PRGs. Active remediation within this area would leave a surface sitewide average at or below the sediment conditions for the surrounding Elliott Bay area. In the Urban footprint area at the end of construction, the remedies will produce a clean surface. This surface would be the result of the placement of clean material for the capping, ENR layer, or residuals management/backfill for dredging. Over the long term, the surface and near surface sediments will reach an equilibrium concentration through mixing and the deposition of new sediment over the post-construction surface. The long-term concentrations for COCs at the Site are expected to be in the range between the natural background levels and the concentrations found in the Elliott Bay region. The Urban footprint, shown in Figure 11-1, has an area of about 30 acres.

- **Study Area Boundary**—The study area boundary footprint is defined by the administrative boundaries that exist for the site, West Waterway OU to the east of the Site, PSR Marine Sediment Unit to the west of the Site, and to the north where sediment concentrations are above the natural background concentrations for those risk-driver contaminants where an extent from the area of historic activities can be defined (see Section 4 and Figure 4-44). Implementing an active remediation to the study area boundary would result in a clean surface at the end of construction. However, in the long term, the sitewide average concentrations for the surface sediments will reach an equilibrium concentration through mixing and the deposition of new sediment over the post-construction surface. The long-term concentrations for COCs at the Site are expected to be in the range between the natural background levels and the concentrations found in the Elliott Bay region. Action taken within this footprint would achieve the maximum level of risk reduction and achievement of the RAOs at the end of construction. The study area boundary footprint, shown in Figure 11-1, has an area of about 40 acres.

Areas beyond these AOPAs are not considered for remediation in this FS and are beyond the area anticipated for any long-term monitoring.

11.1.2 Remedial Action Levels

The RALs are concentrations that are used for making engineering decisions regarding where within an AOPA to apply a technology and when use of the technology is complete. The RALs are not necessarily the same as PRGs. Preliminary remediation goals are the long-term cleanup levels and goals for the project, and may be achieved by active remediation to meet RALs followed by more passive measures such as institutional controls. In contrast, RALs are used to manage active remediation and to define where to begin and when active remedial actions are finished.

Table 11-1 summarizes the RALs for the risk-driver contaminants. Preliminary remediation goals for other COCs for which RALs were not developed are expected to be addressed by the remedial alternatives. The four categories of RALs in Table 11-1 are based on the ability to achieve the PRGs for the different RAOs. The categories of RALs used to develop the alternatives include the following:

- **CSL**—A RAL set to the CSL is used to determine the target for sediments with the highest concentrations present within the AOPA and to determine the application of the appropriate remedial technology (capping, removal, or ENR).

- **SQS**—Surface sediment contamination will be reduced to below the SQS level at the completion of active remediation (use of a technology such as dredging or capping/ENR). A level of two times the SQS is used in some alternatives to determine the appropriateness of applying ENR versus a conventional cap to reduce surface sediment concentrations.
- **Urban**—Surface sediment contamination will be reduced to below the Urban level for risk-driver COCs at the completion of active remediation. For alternatives under the Urban AOPA, the Urban RAL is used to define the area footprint for potential active remediation.
- **RBTC/Natural Background**—Surface sediment contamination will be reduced to near or below the RBTC/natural background levels for the risk-driver COCs at the completion of active remediation. Since the RBTC/natural background levels for PCBs and cPAHs are significantly below the concentrations found in the Elliott Bay area, the application of this RAL can only be applied spatially across the Site to the study area boundary. This RAL can be directly applied vertically for the removal of sediments above RBTCs/natural background within the study area boundary.

Once active remediation is completed, the achievement of the RAO-specific PRGs is determined based on a sitewide average concentration for RAOs 1, 2, and 4, and on a point basis evaluation for RAO 3. For the purpose of determining remedy effectiveness in this FS, there is no assumed longer term reduction of surface sediment concentrations through natural recovery processes or longer term increase due to contribution from off-site sources.

11.1.3 Remedial Action Levels and Remedial Action Objectives

The RALs and how they relate to the RAOs are summarized in the following section.

- **RAO 1—**For the FS, the achievement of the PRGs associated with RAO 1 is assessed on the estimated reduction in the sitewide average residual concentrations for the risk-driver COCs: total PCBs, arsenic, copper, lead, TBT, and cPAHs. Because the PRGs for several of the risk-driver COCs are set to the natural background levels from the Puget Sound "Bold Study" (EPA, 2009a), it is only possible to fully achieve the PRGs at the end of construction for alternatives that take action over the entire study area. In the long term, with sediment mixing and new sediment deposition at the Site, the surface sediment concentrations are likely to increase above the PRGs for RAO 1, especially for PCBs and cPAHs where the sediment concentrations in Elliott Bay are above the natural background concentrations. The RALs therefore provide different levels of incremental

reduction in the sitewide surface average concentration for the COCs. Since at the natural background level the estimated risk for some contaminants exceeds 1×10^{-4}, even the complete achievement of the PRGs for RAO 1 does not result in a reduction of the estimated risk to RBTC levels. Institutional controls are used in conjunction with the remedial activities to address RAO 1 and would likely include regional fish advisories and protecting engineered caps, if placed.

- **RAO 2—**The achievement of RAO 2 in the subtidal areas is based on achieving the most stringent PRG for the subtidal direct contact exposure scenarios (netfishing and tribal clamming) for the risk-driver COCs of arsenic and cPAHs. For arsenic, the PRG for RAO 2 is set to the natural background level, as it is for RAO 1. For cPAHs, the PRG for RAO 2 is 550 µg/kg-dw (see Table 9-5). The achievement of RAO 2 is assessed on a sitewide average basis. The application of the remedial actions based on the RALs defined above is expected to achieve RAO 2.
- **RAO 3**—The RALs appropriate to the risk-driver COCs for RAO 3 are the CSL and the SQS. The achievement of the PRGs for this RAO is expected at the completion of the remedial action. When comparing the post-remediation residual concentrations to the SQS, only immediate post-remediation concentrations are considered and no long-term attenuation is considered. This is a conservative approach because long-term natural recovery, which potentially reduces the surface sediment concentrations, is not included in the evaluation. For the risk-driver COC (total PCBs), the SMS criterion is organic carbon normalized. However, for the purposes of delineation of the extent of risk-driver COCs using the 3-D kriging model, the dry weight values of 1,000 µg/kg and 180 µg/kg for CSL and SQS, respectively, are used. The SQS dry weight value is the SQS criteria of 12 mg/kg organic carbon converted to dry weight based on the average organic carbon content in the sediment of 1.5 percent. For the CSL, the 2LAET value is used because it is equivalent to 65 mg/kg OC.
- **RAO 4**—For RAO 4, total PCBs, copper, and TBT are the risk-driver COCs. The achievement of the PRGs for this RAO is determined on a sitewide basis. Combinations of the previously described RALs are expected to achieve RAO 4 on completion of the remediation.

11.2 ASSEMBLY OF REMEDIAL ALTERNATIVES

Remedial alternatives are developed herein by combining representative technologies and associated process options into logical assemblages that apply to site-specific features. These assemblages generally focus on containment (capping) and removal (dredging) as the primary

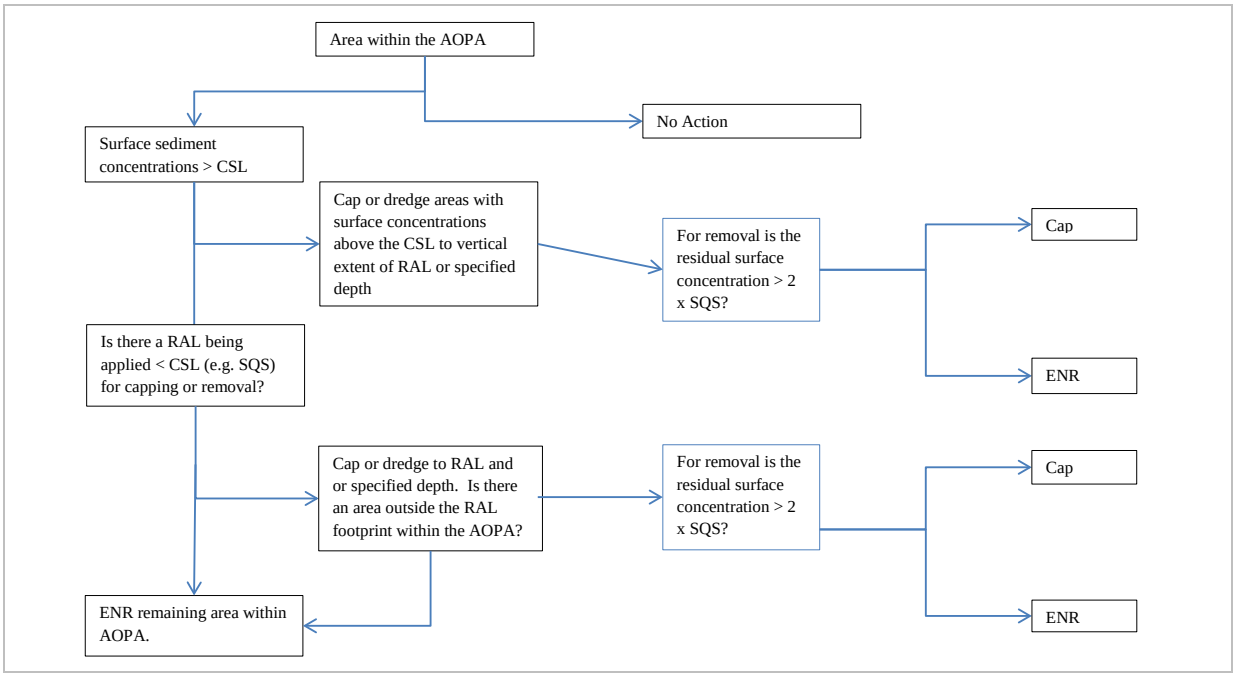
active response actions for reducing risks, but are supplemented by passive measures such as institutional controls as necessary to achieve RAOs.

The development of remedial alternatives is a result of the analyses and findings in previous sections of this RI/FS. These include the following:

- The regulatory requirements (e.g., ARARs), RAOs, and PRGs that were identified in Section 9;
- The areas of potential action that were discussed above and identified by the nature and extent of contamination evaluation in Section 4;
- RALs (discussed in Section 11.1 and presented in Table 11-1); and
- Representative remedial technologies that were screened in Section 10.

The first step in developing remedial alternatives was to determine the areas of the Site that were appropriate for specific remedial technologies. The application of remedial technologies in developing the alternatives was determined according to the process shown in the flowchart below.

Alternative Remedial Technology Decision Process



AOPA = area of potential action; CSL = cleanup screening level; ENR = enhanced natural recovery; RAL = remedial action level

The process begins with the selection of an AOPA as defined in Section 11.1.1. Within this AOPA, the area where the surface sediment concentration of any risk-driver COC is above the CSL is determined and the area is designated for capping or removal (because these are the two technologies capable of addressing that level of contamination). If a removal action is completed, a further evaluation of the new surface is completed to determine if surface contamination is in excess of 2 x SQS. The threshold of 2 x SQS is the level below which ENR is assumed in the FS to be effective based on the description of applying ENR at the Lockheed West Site (Section 10.6). If the surface concentration exceeds this threshold, a cap is required for that area; otherwise the placement of ENR is identified as appropriate for the post-removal surface. An alternative may include additional removal or capping to a RAL more conservative than the CSL (e.g., SQS, Urban); otherwise, the area of the AOPA that is outside of capping or removal will have ENR applied.

Technologies were applied based on four general alternatives: no action, containment-focus, removal-focus and complete removal. These general alternatives were further divided into subalternatives based on the different AOPAs and RALs where the specific remedial technologies could be applied according to the decision process described above. Table 11-2 presents the remedial alternatives, the RALs, actively remediated areas, and volumes of sediment removed. The alternatives were assembled by combining one or more of the retained technologies/process options presented in Sections 10.4 through 10.11 (see Tables 10-12 and 10-13). The alternatives encompass a range of management strategies from *in situ* containment to removal and off-site disposal of impacted sediments. Figures 11-2 to 11-17 illustrate the components of each alternative.

The general remedial alternatives and the goals that each alternative is designed to achieve are as follows:

- **Alternative 1 – No Action**. This alternative provides a baseline against which to compare the other remedial alternatives; inclusion is required by CERCLA.
- **Alternative 2 – Containment-Focus**. This alternative would contain risk-driver COCs in all areas by conventional capping and/or ENR where risk-driver COC concentrations are greater than RALs. This general alternative includes nine subalternatives (i.e., 2A1, 2A2a, 2A2a Plus, 2A2b, 2A3, 2A4a, 2A4b, 2A4c, and 2B) to address the range of

AOPAs and RALs. Alternative 2A2a Plus was developed at the request of EPA; see Appendix I.

- **Alternative 3 – Removal-Focus**. This alternative would dredge sediments with the highest concentration of risk-driver COCs, dispose of the removed sediments off-site, and contain residual risk-driver COCs in removal areas and in all remaining areas by conventional cap or ENR where risk-driver COC concentrations are greater than RALs. This general alternative includes six subalternatives (i.e., 3A1, 3A2, 3A2 Plus, 3B, 3C, and 3C Plus) to address the range of AOPAs and RALs. Alternatives 3A2 Plus and 3C Plus were developed at the request of EPA; see Appendix I.
- **Alternative 4 – Complete Removal**. This alternative would remove all areas within the Lockheed West Site where risk-driver COC concentrations are greater than RALs within the AOPA footprints with off-site disposal of sediments. This general alternative includes three subalternatives (i.e., 4A, 4B, and 4C) to address the range of AOPAs and RALs.

The various technologies that were carried through screening are represented consistently among the remedial alternatives in the following ways:

- Remedial alternatives rely on active remediation and institutional controls to protect human health pursuant to achieving RAO 1. Additional institutional controls are used for long-term protection of engineered containment. All of the alternatives (except Alternative 1 (No Action) and Alternative 4) include sitewide long-term monitoring to assess risk reductions relative to RAO 1. All alternatives include post-dredging confirmation sampling at the end of construction to verify remedy completion.
- Dredging and disposal are the primary process options for the alternatives that include removal.
- Upland off-site disposal is incorporated into all remedial alternatives where there is sediment removal.
- Capping and ENR are incorporated into all the containment- and removal-focus remedial alternatives. ENR is used where considered acceptable based on sediment chemistry concentrations; capping is used where ENR is not considered acceptable, and partial dredging and capping are used when elevation constraints preclude capping (e.g., shoreline areas).

Common remedy elements for each of the alternatives are discussed in the following section. A detailed description of each remedial alternative is provided in Section 11.4. The components of the alternatives are illustrated in Figures 11-2 to 11-17.

11.3 COMMON REMEDY ELEMENTS

This section provides additional details pertinent to all remedial alternatives. Common remedy elements discussed in this section are summarized below in a text box that provides a roadmap for the section.

Common Remedy Elements	
Common and Technology-Specific Engineering Assumptions and Considerations	**Common Remedial Actions**

• Remedial Technology Assignments (Table 11-3)
• Site Access, Preparation, and Staging
• Capping and ENR
• Removal
  o Volume estimates
  o Residuals management
  o Dredge water management
  o Transloading and upland disposal
  o Slope stability
• Cost and Construction (Table 11-4)
	• Former Shipway Area Remediation[1]
	• Shoreline/Intertidal Remediation and Habitat Improvements
	• Institutional Controls
	• Monitoring[1/]

1/ An alternate approach to Former Shipway Area Remediation and Monitoring applies to Alternative 3C Plus; see Appendix I

11.3.1 Common and Technology-Specific Engineering Assumptions and Considerations

This section discusses physical and logistical constraints and considerations related to implementation of all remedial alternatives and the engineering assumptions made to address them in the FS.

11.3.1.1 Remedial Technology Assignments

The spatial extent of active remediation is developed for each alternative based on the extent of RAL exceedances. The remedial technologies are then assigned based on whether the alternative is focused on containment or removal technologies.

The technology assignments and considerations for the technology applications applied to all remedial alternatives are summarized in Table 11-3. The criteria used for technology assignments included contaminant upper limits, contamination thickness, physical site conditions, and habitat and navigation elevation requirements.

The contaminant upper limit of each technology is the highest concentration that is assumed can be remediated under site conditions to achieve the identified goals for the technology. Removal and capping technologies do not have any contaminant upper limits. Sitewide, the upper concentration limit for ENR is defined as two times the RAL (i.e., SQS), except in intertidal areas, where active remedial technology (e.g., dredge and cap) is assigned as a default action and included as a common remedy element. The vertical extent of contamination is defined as the depth of RAL exceedances.

Applicability of each remedial technology has location-specific physical considerations (e.g., former shipway area, shoreline/intertidal areas, and areas with steep slopes). Habitat areas are defined as the areas at elevations above -10 feet MLLW. Elevation requirements for evaluating applicability of remedial technologies also include navigation areas with authorized maintenance elevations (i.e., West Waterway). In a navigational channel, capping is assumed to be restricted to areas where the existing surface sediment elevation provides adequate clearance for navigation. Such clearance requirements are considered during technology assignments and are summarized in Table 11-3.

11.3.1.2 Site Access, Preparation, and Staging

Site access will be coordinated by identifying the security screening and site use criteria for the Port's Homeland Security personnel, security requirements for waters adjacent to Port facilities, and compliance with Transportation Worker Identification Credential requirements.

Site preparation for sediment remediation projects is generally limited to clearing the remediation and associated operational areas of debris and other obstructions as needed on a site-specific basis. Staging for sediment remediation projects refers to upland operational areas that support material and equipment handling to and from the in-water project site.

The nature and extent of debris will be determined during remedial design. Standard practice in environmental dredging operations is to remove large debris, such as logs, concrete, and boat hulls, before commencing sediment removal. In this FS, both containment and removal alternatives incorporate the assumption that some degree of debris removal is required and will be conducted using a derrick barge and clamshell dredge. The debris will then be barged and

offloaded at a transfer facility for subsequent shipment to an upland landfill or for potential recycling and beneficial reuse.

Piling and pier removal is not considered part of the general site preparation. The Port and DNR will determine the final disposition of these pilings and piers subject to the terms of the lease termination agreement between the Port and DNR (DNR, 2007) though the EPA has expressed an expectation that the pilings will be removed by the time a remedy is implemented. However, piling and pier removal is part of the complete removal alternative (Alternative 4) and subalternatives of Alternatives 2 and 3 where dredging is included to fit the cap with the goal of minimizing changes to existing water elevations of the site. Since closure of the shipyard in 1987, decking and pilings of Piers 21 and 22 have been removed and the decking has been removed from Piers 23 and 24 although the pilings remain. The former shipway, as documented in the *RI Data Report,* has had much of the infrastructure removed but all the pilings remain in place.

Staging areas refer to upland operational areas that support material and equipment handling to and from the in-water project site. Upland staging areas are needed to support land-based operations such as transloading of dredged sediment intended for upland landfill disposal, equipment and material transfers to barges, as well as general construction support activities. For the FS, suitable land is assumed to be available adjacent to the Lockheed West Site, such as the upland Terminal 5 site, for staging and support activities, such as equipment and raw material staging or a sediment treatment facility. Specific staging areas have not been identified, and only rough assumptions have been made about specific staging area requirements. An allowance is included in the cost estimates for each alternative to account for leasing, site preparation, and set-up of an upland staging facility.

11.3.1.3 Capping and ENR

It is assumed that conventional sand caps will be used for alternatives involving containment of contaminated sediment. During design, USACE capping guidance will be used to determine the thickness and gradation of the cap (Palermo et al., 1998; Clarke et al., 2001) based on evaluation of various factors including bioturbation, consolidation, erosion, operational considerations such as propeller scour, and chemical isolation. For this FS, a sand cap thickness of 3 feet has been

assumed in all cap areas. Thinner or thicker caps may be developed during remedial design depending on the COCs and for elevation considerations such as navigation depths or to accommodate unrestricted use of benthic resources.

The gradation of cap material depends on factors such as habitat, erosion, and scour potential. No assumptions regarding a specific material gradation have been made for this FS because the range of material unit costs for sand capping material of different gradations is very narrow and is not expected to have a significant impact on estimated costs. All cut slopes to be capped will likely need a riprap toe as a buttress. Armoring requirements will be determined on a site-specific basis in the design phase.

Although composite and reactive caps have not been carried forward into the development of preliminary alternatives, the consideration of such technologies during the design is not precluded. Some of the potential benefits from using composite and reactive caps are the ability to achieve remedial objectives while limiting costs, avoiding disruptive activities, or providing future use opportunities. These benefits can be achieved within the FS cost estimate contingencies. Above elevation -10 feet MLLW, some sediment removal may be required in certain areas to accommodate the cap thickness without impacting intertidal habitat areas.

In navigation areas with authorized maintenance elevations, capping is assumed to be restricted to areas where the existing surface sediment elevation provides adequate clearance for navigation. These areas include portions of former Dry Dock #1 and portions of the West Waterway navigation channel located outside (east) of the Outer Harbor Line. For this FS, it is assumed that any proposed capping of sediments would be applied by allowing at least a 10-foot horizontal buffer between the West Waterway navigation channel and the edge of the cap and a 4-foot differential depth between the top of the cap and the deepest permitted maintenance depth. This depth would allow for a 2-foot clearance for safety and a 2-foot maintenance over-dredge. The West Waterway navigation project depth is -34 feet MLLW as established by the USACE (NOAA, 2010).

Enhanced natural recovery is included in areas where COCs are greater than RALs after active remediation; however, conventional isolation capping is not required to achieve RAOs (see Section 10.5). During design, the ENR material will be evaluated to ensure that the placed ENR

layer is appropriate for benthos in the area and the ENR thickness will be determined based on the surface COCs concentrations, so that ENR would result in a surface layer with contaminant concentrations within acceptable levels. This FS was prepared with the assumption that ENR would involve spreading an average of 12 inches of sand to achieve a minimum 6 inches of coverage everywhere it is applied.

All in-water construction of capping and removal would be conducted during the designated in-water work window (i.e., June 15 through February 15), although this official work window may be limited based on site-specific factors. The final work window will be defined and coordinated in consultation with the Tribes and other resource agencies before implementation.

Contingencies for repair of capping or ENR layers as part of O&M are included in the cost estimates for capping and ENR. Costs assumptions are presented for each alternative in Appendix F.

11.3.1.4 Removal

Removal may be performed by any of the technologies identified in Section 10.7. Based on recent experience at similar sediment remediation projects in the region, mechanical dredging with a conventional barge-mounted clamshell dredge and/or environmental bucket is assumed as the process option for this FS. Conventional excavation technologies, such as backhoes, loaders, or barge-mounted precision excavators, are applicable to shallow water operations such as shoreline areas, exposed intertidal areas, and debris removal activities, as necessary.

In Alternatives 2, 3, and 4, it is assumed that between mean higher high water (approximately +11.3 feet MLLW) and -10 feet MLLW (i.e., habitat areas), dredged surface must be restored to approximate pre-dredge bathymetry. Dredging will therefore be followed by backfilling with sand to approximate pre-existing grades. Refer to the common remedy element for shoreline/intertidal habitat improvements for details of the proposed remedy at habitat areas (Section 11.3.2.2).

Volume Estimates

The 3-D sediment contamination visualization software, C Tech MVS, utilized for determination of the nature and extent of COCs (see Section 4.9.3) was also used for volume calculations of

contaminated sediments for removal alternatives. The depth of removal varies based on the extent of COCs and the RAL. The model computes a neat-line removal volume by interpolating the depth of COCs at the specified remedial action level between the cores. In addition to this 3-D model, AutoCAD/Civil3D software was used to compute quantities for alternatives that involve removal to fit a conventional cap where changes in the existing water depths are to be minimized. Removal volume estimates for all alternatives and the proposed design profiles for dredge to fit cap scenario are presented in Appendix E.

The estimated volumes are neat-line dredge volumes, which are the required limits of removal for FS-level analysis purpose. The dredge prisms will be refined during design for dredge operational considerations. Typically, contingency volumes are included to account for volume creep that occurs during design. Other contingencies that should be applied to the neat-line dredge volumes include a typical 1.0-foot overdredging allowance, allowance to account for additional sediment characterization (i.e., presence of contaminants beyond the currently estimated depth of contamination), typical clean-up passes for residuals management, and dredge cut-slope stability issues that are identified during design. To account for these various causes of volume creep, estimated dredge neat-line volumes are increased by 50 percent. This adjustment is supported by the findings of a recent study on *in situ* volume creep for environmental dredging projects (Palermo and Gustavson, 2009), which recommends that, for FS-level considerations, an adjustment factor of 50 percent (that is, an estimated dredge prism volume equal to 1.5 times the neat line prism volume) is appropriate for typical Site conditions.

Residuals Management

Section 10.7.3 discusses management of residuals during removal. Dredging typically causes a degree of resuspension of contaminated sediment that settles back onto the dredged surface. Operational in-water controls are typically developed during remedial design to manage residuals.

Depending on depth of removal and levels of contamination remaining at the dredged surface, residuals management, ENR, or a sediment cap may be required following removal in some areas (and would be implemented as described in Section 11.4.2). For the purposes of the FS, it

is assumed that removal below -10 feet MLLW will be followed by placement of 9 inches of sand layer backfill to achieve 6 inches of coverage over the dredge footprint.

Dredge Water Management

It is a standard practice in remedial dredging to dewater the dredged sediment on the dredge scows and allow the water to discharge back within the active dredge area. Appropriate best management practices (e.g., hay bales and filter fabric) are installed to filter the discharges to maintain compliance with water quality criteria established for the dredging operations. It is assumed that dewatering water is released within the limits of the dredge operating area, subject to compliance with water quality criteria.

The dredged water may need to treated before it is allowed to discharge based on the water quality compliance criteria. To account for such treatment, the FS-level cost estimates include a contingency for discharge of dredged water to the sewer and publicly owned treatment works under permit with the King County Industrial Waste program.

Water management is also a necessary part of dredged material transloading operations. Stormwater and drainage from sediments generated in the transloading facility are assumed to be captured, stored, treated, and either discharged to the local sanitary sewer under a King County Discharge Authorization or returned back to water subject to water quality compliance criteria.

As discussed in Section 10.10, two regional Subtitle D landfills (Allied Waste Inc., in Roosevelt, Washington, and Waste Management in Arlington, Oregon) are both permitted to receive wet sediment, which is sediment that does not pass the paint filter test, and are assumed in this FS as the upland disposal facilities for removal alternatives. Any additional accumulated free water during transfer of dredge material in lined shipping containers will be managed by the landfill facility.

Transloading and Upland Disposal

The dredged material placed into the barge will be transported to a transloading facility where the material will be transferred to railcars for disposal at the landfill. The availability and capacity of a commercial transloading and transportation facility to manage dredged material is not currently established. Allied Waste, Inc., has leasing arrangements with a private property

owner along the Lower Duwamish Waterway and can perform transloading operations that involve direct transfers from a barge to lined bulk-material shipping containers (AECOM, 2010). The containers will then be transferred to rail at the Burlington Northern Santa Fe Railway intermodal facility at Hanford Street and hauled to the Roosevelt Regional Landfill near Roosevelt, Washington, or Columbia Ridge Landfill in Arlington, Oregon. Other methods of transloading sediment, such as direct container loading on barges, may also be considered during remedial design. The logistics and actual capacity of the transloading operations will also be determined during remedial design.

This FS assumes that removal alternatives include transloading operations up to delivery of full containers to an intermodal facility are part of the remedial action. The cost estimates include establishing a transloading facility, transport of dredged sediments to a transloading facility, and the sediment rehandling at the transloading facility, which includes material transfer from barge onto lined bulk material shipping containers, transfer of loaded containers onto trucks, and truck transport of the containers to an intermodal facility for transfer to rail.

Slope Stability

Riprap can be utilized to stabilize cap slopes and prevent erosion and sloughing. These areas would include dredged slopes and cap slopes, which would be analyzed by current geotechnical and coastal engineering practice during remedial design. The analyses regarding stability of slopes would include wind and wave analysis, static and seismic slope stability analyses, and armoring design. To the extent that habitat between mean higher high water and -10 feet MLLW areas is intended as habitat mitigation and/or restoration, options for improving habitat will be discussed with NOAA and the other natural resource agencies. Also, any habitat improvement or restoration proposed on State-Owned Aquatic Lands will obtain, if required, the authorization from DNR and the Port.

Dredging in sloped areas would be carefully evaluated during remedial design to prevent sloughing and slope failure. In some cases, these considerations are expected to preclude complete removal of contaminated sediments in nearshore areas and capping would then be used to reduce exposure to the remaining contaminated sediment. Existing shoreline slopes are approximately at 1 vertical to 2 horizontal ratio (approximately 26 degrees) or flatter. For this

FS, dredging and capping slopes are assumed to be at 1 vertical to 3 horizontal ratio (approximately 17 degrees) or flatter. Shoreline cap slopes will be armored with riprap as needed to ensure the long-term stability of the slopes following the remedial action. All cut slopes will likely need a riprap toe during construction of conventional cap along the slopes. Treatment of shoreline areas will be coordinated during remedial design with EPA, the stakeholders, and the Tribes. In the middle of the north face of Terminal 5, the large riprap currently serving as shoreline protection will remain in place; however, habitat/fish mix may be placed in the interstices of this riprap to provide a more favorable environment for aquatic species. Similarly, all riprap armor material placed along the shoreline will then be covered with granular habitat mix.

11.3.1.5 Cost and Construction

The area-specific volume and construction assumptions used in developing FS remedial costs are presented in Table 11-4. The detailed cost estimates are described in Appendix F and have been developed consistent with CERCLA guidance (EPA, 2000b) with a target accuracy of +50 percent and -30 percent.

11.3.2 Common Remedial Actions

This section describes remedial actions that are common to all remedial alternatives and include the former shipway area remediation, shoreline and intertidal habitat remediation and improvements, institutional controls, and monitoring.

11.3.2.1 Former Shipway Area Remediation

Alternatives 2, 3, and 4 include remediation of the former shipway area. An alternate approach to Former Shipway Area Remediation applies to Alternative 3C Plus; see Appendix I. As discussed in the *RI Data Report*, sand blast grit was reported to cover the upland area near the shipway to a depth of 0.5 foot or more. Currently, the shipway area has had much of the infrastructure removed but all the pilings remain in place. The remediation of the area will include removal, to the extent possible, of sandblast grit and sediments from the shipway area by either operating low ground pressure excavation equipment during periods of low tide, by a precision excavator from barge, or a vacuum truck operation at low tide to the extent practical, followed by capping the area with a minimum 3 feet of sand and blending the sand cap with the PSR beach next to the

former shipway. Figure 11-2 illustrates the proposed remedy elements (e.g., removal, cap, and habitat mix) for the former shipway area.

11.3.2.2 Shoreline/Intertidal Remediation and Habitat Improvements

Alternatives 2, 3, and 4 will involve general cleanup and removal of certain existing shoreline structures (e.g., debris piles, remaining derelict bulkhead, and some pilings) and implementation of shoreline stabilization, habitat improvements, and mitigation and/or restoration measures as applicable. Natural resource trustees will be consulted on ideas for shoreline and habitat improvements (e.g., type of habitat mix to be used).

Derelict bulkheads and piers will be removed and demolished. Areas of existing riprap located along the shoreline (see Tetra Tech, 2008b) are not anticipated to be removed. Habitat mix will be placed over existing riprap areas. Cost estimates include the assumption of dredging and backfilling of shoreline slopes from the edge of existing riprap to the landward edge of the study boundary and extending to the riprap armor around the northeast corner of the site. Refer to Figure 11-2 for an illustration of the proposed shoreline remediation area that is a common element of each alternative.

Where practicable, shoreline and intertidal areas for remedial alternatives that involve capping or dredging will include provisions to improve the existing habitat. Such provisions may include grading features to increase or improve valuable intertidal habitat areas, riparian plantings, and other habitat features. A goal of this FS is to develop and select a remedy that involves no net loss of intertidal habitat. The details of shoreline remediation (i.e., limits of removal, backfill thickness, and design of riprap armoring) will be determined during remedial design.

11.3.2.3 Institutional Controls

Major types of institutional controls considered for this FS are governmental controls (i.e., monitoring and notification of waterway users), proprietary controls (i.e., deed restrictions and restrictive covenants), enforcement and permit tools (i.e., permits, consent decrees), and informational devices (i.e., public outreach and education, seafood consumption advisories, enforcement tools, and a site registry).

In Washington State, the Department of Health issues seafood consumption advisories to warn the public of possible toxicological threats from consuming certain fish species from certain water bodies. Currently there is a regional Puget Sound fish advisory for Marine Area 10 – Seattle/Bremerton area, which includes Elliott Bay, Duwamish Waterway, Eagle Harbor, and Port Orchard Waterway (DOH, 2011). The current fish advisory for Elliott Bay includes no rock fish consumption and no more than 2 meals/month flatfish consumption. This regional seafood consumption advisory is applicable to all alternatives even if complete dredging to the PRGs occurs at the Site. This is because the RBTCs for some risk-driver COCs are below the PRGs and the resulting calculated risks are at 2×10^{-4}, and because the fish advisory is not solely due to contamination at this site. Consistent with the regional advisory, a sitewide fish advisory will be applicable to all alternatives. The alternatives with a removal component may also require short-term fish consumption advisory due to short-terms impacts during remedial construction when the highest sediment contaminant concentrations are being actively dredged.

Public outreach and education would likely be similar in scope for all remedial alternatives. In general, EPA's approach regarding these institutional controls is that education and outreach programs should not be continued forever because the goal is for improvement in fish tissue concentrations throughout the whole Elliott Bay over time. For the FS analysis, these programs are assumed to be common for all alternatives and continue for a 30-year period. The other institutional controls would likely vary in scope depending on the remedy plan of each alternative such as post-remediation water depths and the size of the capping areas.

Proprietary controls, monitoring and notification of waterway users, enforcement tools, and a site registry would apply in proportion to the area of the Site remediated by capping. These controls would not be needed for the areas remediated by dredging or ENR, which would not restrict any future use of the Site. ENR will be applied where the surface sediments have relatively low levels of contamination that require some remedy action while the underlying near surface sediments are generally less contaminated. The ENR application will be designed such that a clean surface layer will be achieved immediately after thin-layer placement; this layer, which will contain contaminant concentrations within acceptable levels, will be maintained long term at steady-state conditions, due to the mixing of clean new material and existing surface sediments through bioturbation and other mechanisms (e.g., wind and wave action, scour). In other words,

ENR is not an isolation cap but a thin-layer placement where natural and future site use mixing activities will be allowed and result in acceptable steady-state equilibrium concentrations. Therefore, ENR would not result in future use restrictions of the Site and accordingly proprietary controls, monitoring and notification of waterway users, enforcement tools, and a site registry would not apply to ENR areas. Although institutional controls are not required for ENR areas, long-term monitoring will be required to ensure ENR's long-term effectiveness and protectiveness (see Section 11.3.2.4). Institutional controls expected to be used for each remedial alternative are presented in Section 11.4 and discussed under the detailed evaluation of each alternative in Section 12. Costs for institutional controls are incorporated into the cost estimates for each remedial alternative in Appendix F. The estimates include a present value analysis for a 30-year period for an initial cost and annual cost for public outreach and education, seafood consumption advisories, deed notice filing, proprietary controls, agency reporting, and review. The cost estimates of the alternatives with a capping component do not include a third-party settlement fee for future use restrictions in commerce and navigation due to capping. Because the Site is a tribal U&A area, a remedy should be designed to reduce conflicts or restrictions on tribal treaty fishing rights or other treaty protected rights such as anchorage of tribal fishing vessels or access to aquatic resources. Therefore, any restriction on anchorage and grounding of tribal vessels or to access the resources will be minimized or eliminated during the remedial design (e.g., applying a thick cap). For the FS evaluation, these restrictions were considered common institutional controls applicable to cap areas and incorporated into the detailed and comparative evaluation of the alternatives against NCP's threshold and primary balancing criteria in Sections 12 and 13.

11.3.2.4 Monitoring

Monitoring is a key assessment technology for sediment remediation to verify achievement of project RAOs. For this FS, two monitoring categories are assumed: 1) construction monitoring, which is short-term monitoring during construction to ensure performance of the operations; and 2) long-term O&M monitoring, which is to confirm that technologies are operating as intended.

Construction monitoring ensures quality assurance/quality control of the construction through bathymetric surveys and verification sediment sampling and also confirms that human health and the environment are adequately protected during construction through water quality monitoring.

It is assumed that long-term monitoring will be needed for each of the alternatives with the exception of Alternative 4 (complete removal). Complete removal alternatives may require monitoring immediately after construction to assess potential recontamination in addition to monitoring during construction. The scope of the monitoring program and associated EPA site reviews will vary depending on the selected remedy.

For Alternatives 2 and 3, construction performance monitoring will immediately assess whether the cap has been affected by residuals. Long-term O&M monitoring will assess cap stability and effectiveness to ensure that the cap is placed as intended and is performing the isolation function. The details of long-term monitoring, performance standards and benchmarks, and associated contingency actions will be outlined in an OMMP to be developed prior to construction. The OMMP will cover post-construction monitoring and maintenance activities that are required to ensure the long-term performance of the remedy. The OMMP will also outline performance expectations and potential courses of action that should be taken based on sampling results, the passage of time, the influence of marine activities including any marine construction, or the occurrence of natural phenomena such as earthquakes or significant weather events. The monitoring results may be used to identify the need for supplemental sand placement. For the FS-level evaluation, the long-term O&M cost estimates for monitoring cap stability was presented for a 30-year period per EPA guidance; however, the O&M requirements associated with a cap will be in place indefinitely. For this FS, long-term O&M monitoring of cap areas is assumed to include surface and subsurface sediment chemistry surveys to monitor any recontamination and the isolation performance of the cap, resident clam tissue sampling to monitor protectiveness of the remedy for clamming, sitewide bathymetry to make sure the cap integrity remains as designed and constructed, and sediment profile imaging camera surveys to monitor the cap thickness and observe the benthic community. Long-term O&M monitoring of ENR and unremediated areas within the study area boundary is assumed to include surface sediment chemistry surveys, resident clam tissue sampling, sitewide bathymetry, and sediment profile imaging camera surveys. Cost estimates of each alternative include construction monitoring and long-term monitoring cost estimates as applicable and are presented in Appendix F.

11.4 DETAILED DESCRIPTION OF REMEDIAL ALTERNATIVES

This section provides a detailed description of each alternative. Alternative variations 2A2a Plus, 3A2 Plus, and 3C Plus are described in Appendix I. Table 11-5 presents a summary of actively remediated areas, volumes, and FS-level costs associated with each remedial alternative. Figures 11-3 to 11-17 illustrate the components of each alternative. Appendix F provides detailed cost estimates. It is anticipated that the potential differential costs would be captured within -30 percent to +50 percent accuracy of the initial FS-level cost estimate used for alternative development.

11.4.1 Alternative 1— No Action

The NCP at 40 CFR 300.430(e)(6) provides that the No Action alternative should be considered at every site (EPA, 2005b). The No Action alternative should reflect the site conditions described in the baseline risk assessment and remedial investigation. Under this alternative, no active remedial actions would be taken.

The risk assessments showed unacceptable risks to human health and the environment (Tetra Tech and Pascoe, 2009a,b). Therefore, this alternative does not appear to meet the RAOs but has been included consistent with NCP requirements for use as a remedy standard of comparison.

11.4.2 Alternative 2— Containment-Focus

Under this general alternative, conventional sediment capping and ENR would be used to contain contaminated sediments within the remedial action area, creating a clean surface suitable for re-establishment of aquatic biota. The cap would be of sufficient thickness and gradation to ensure isolation of impacted sediments and to withstand natural and vessel-related erosion forces. ENR is not presented as a containment methodology even though it may provide some containment benefit immediately after construction. The capping and ENR material would be placed using conventional mechanical dredging equipment or other common placement methods. This remedy alternative is designed to achieve RAO 1 through a combination of active remediation and institutional controls, achieve the PRGs for RAOs 2 and 4 on a sitewide average basis and the PRGs (i.e., SQS) for RAO 3 on a point basis immediately following construction, and be protective of human health and the environment immediately upon completion.

Common elements of this alternative include the following:

- Removing debris in all areas that would prohibit cap or ENR placement and effectiveness;
- Installing a conventional cap in high concentration areas and ENR in low concentration areas to a specific surface sediment RAL footprint;
- Leaving existing piling and pier structures in place unless they prevent placement of the capping materials (see description of Alternative 2B). (Note: the Port and DNR will determine the final disposition of these pilings and piers subject to the terms of the lease termination agreement between the Port and DNR (DNR, 2007) though the EPA has expressed an expectation that the pilings will be removed by the time a remedy is implemented);
- Performing former shipway area remediation, shoreline remediation, shoreline stabilization, intertidal habitat restoration, and improvements;
- Implementing a long-term monitoring O&M program to verify performance of the cap and to respond to potential cap damage; and
- Employing institutional controls (public outreach, education and seafood consumption advisories sitewide; proprietary controls, monitoring and notification of waterway users, enforcement tools, site registry to apply to conventional capping areas).

This general alternative is divided into eight subalternatives based on various AOPAs and RALs considering existing water depths and future site use.

11.4.2.1 Alternative 2— Containment-Focus

The Alternative 2A containment-focus alternatives are defined by placing a cap/ENR over surface sediments based on varying AOPA footprints: SQS, Urban, and study area boundary.

Alternative 2A1

Alternative 2A1 involves conventional capping over the area defined by the risk-driver CSL footprint and ENR over the remaining area to the SQS AOPA footprint. Figure 11-3 illustrates the capping and ENR remedial footprints. Under this alternative, about 18 acres of subtidal sediment would be remediated. Shoreline and the former shipway remediation areas (about 2 additional acres and removal of approximately 10,000 cubic yards) are also included. Institutional controls would include seafood consumption advisories and public outreach and education on a sitewide basis; in addition, proprietary controls (e.g., notification of waterway

users, enforcement tools, site registry) would apply to the designated conventional cap area of about 10 acres.

Alternatives 2A2a and 2A2b

Alternatives 2A2a and 2A2b involve conventional capping over the areas defined by the risk drivers to the CSL or SQS footprints, respectively, and ENR over the remaining area to the Urban AOPA footprint. Figures 11-4 and 11-5 illustrate the capping and ENR remedial footprints for Alternatives 2A2a and 2A2b, respectively. Under these alternatives, about 30 acres of subtidal sediment would be remediated; they only differ by the area covered by a conventional cap (i.e., 10.3 acres for Alternative 2A2a and 18 acres for Alternative 2A2b). The same elements of shoreline and former shipway remediation and institutional controls as Alternative 2A1 would be applied under these alternatives.

Alternative 2A3

Alternative 2A3 involves conventional capping over the area defined by the risk-drivers to the CSL footprint and ENR over the remaining area to the study area boundary. Figure 11-6 illustrates the capping and ENR remedial footprints. Under this alternative, about 40 acres of subtidal sediment would be remediated, with about 10 acres of conventional cap. The same elements of shoreline and former shipway remediation and institutional controls as Alternative 2A1 would be applied under this alternative.

Alternatives 2A4a, 2A4b, and 2A4c

Alternatives 2A4a, 2A4b, and 2A4c involve conventional capping to the SQS, Urban, or study area boundary AOPA footprints. Figures 11-7, 11-8, and 11-9 illustrate the capping remedial footprints for each alternative. Under these alternatives, about 18, 30, or 40 acres of subtidal sediment would be remediated by a conventional cap, respectively. Alternative 2A4c is the only containment-focus alternative that would meet RAO1 PRGs at the completion of construction. The same elements of shoreline and former shipway remediation and institutional controls as Alternative 2A1 would be applied under these alternatives. However, under these alternatives, more extensive institutional controls and future use restrictions would likely need to be considered because these alternatives would modify existing elevations and would limit future uses to a much greater degree than other alternatives.

11.4.2.2 Alternative 2B— Containment-Focus with Removal – Minimize Changes to Water Depth

Similar to Alternative 2A3, this alternative would cap surface sediments in areas above the CSL footprint but would also include removal of sediments within the capping footprint to fit the 3-foot conventional cap with the goal of minimizing changes to existing water depths. The Port's request for the preservation of existing uses by maintaining current water depths (Port of Seattle, 2010) is considered in this alternative by removal of elevated sediment areas to a depth of equal or greater than 3 feet to accommodate cap placement and not changing the existing water depths at the Site. Enhanced natural recovery would be applied in remaining areas to the study area boundary. Figure 11-10 illustrates the removal, capping, and ENR areas. Under this alternative, about 40 acres of subtidal sediment would be remediated and 51,800 cubic yards of contaminated sediment would be removed. The same elements of shoreline and former shipway remediation and institutional controls would be applied under this alternative as for Alternative 2A1. Removal volume estimates and proposed design profiles for Alternative 2B are presented in Appendix E.

11.4.3 Alternative 3— Removal-Focus

This removal-focus remedial alternative includes removal of contaminated sediments with risk-driver COCs elevated above specific RALs and capping/ENR of the residuals, as appropriate. The remainder of the Site where the COCs are greater than specific RALs would be actively remediated by a conventional cap or ENR. The sediment would be mechanically dredged, transferred from barge to lined shipping containers, and trucked to a rail transfer facility for transport to a regional landfill facility. This remedy alternative is designed to address contaminant mass removal concerns and to achieve RAO 1 through a combination of active remediation and institutional controls, achieve the PRGs for RAOs 2 and 4 on a sitewide average basis and the PRGs (i.e., SQS) for RAO 3 on a point basis immediately following construction, and be protective of human health and the environment immediately upon completion.

Common elements of this alternative include the following:

- Removing debris;

- Dredging and upland disposal (see descriptions of Alternatives 3A, 3B, and 3C for dredge areas and dredge volumes);
- Transporting sediment via rail for disposal at a permitted upland landfill facility;
- In dredged areas, managing dredging residuals;
- Actively remediating other areas by conventional cap or ENR where risk-driver COCs are greater than RALs;
- Performing former shipway area remediation, shoreline remediation, shoreline stabilization, intertidal habitat restoration, and improvements;
- Implementing a long-term monitoring O&M program to verify performance of the conventional cap and to respond to potential cap damage, and
- Employing institutional controls (public outreach, education and seafood consumption advisories sitewide; proprietary controls, monitoring and notification of waterway users, enforcement tools, site registry to apply conventional capping areas).

This alternative is divided into four subalternatives based on various AOPAs and RALs considering high concentration materials in former operational units, existing water depths, and future Site use.

11.4.3.1 Alternative 3A— Removal-Focus – Remove up to 3 Feet over CSL or SQS Surface Sediment Footprint

This removal-focus alternative is included to address mass removal of the most impacted sediments. It would not change water depth elevations in areas needing a conventional cap and is not bounded by former shipyard operational areas (e.g., dry docks). Capping/ENR footprints would be based on the horizontal extent of contamination based on the Urban AOPA footprint.

Alternative 3A1

Alternative 3A1 involves removal of up to 3 feet of sediment over the area defined by the risk-drivers to the CSL footprint, placing a conventional cap over residual contamination greater than two times the SQS, and performing ENR over the remaining area to the Urban AOPA footprint. Figure 11-11 illustrates the removal, capping, and ENR areas. Under this alternative, about 30 acres of subtidal sediment would be remediated and would include removal of 55,500 cubic yards of contaminated sediments. Shoreline and former shipway remediation are also included as part of the alternative, as discussed above under Section 11.3.2, Common Remedial Actions, and

includes about 2 additional acres and removal of approximately 10,000 cubic yards. Institutional controls would include seafood consumption advisories, public outreach, and education on a sitewide basis; proprietary controls (e.g., notification of waterway users, enforcement tools, site registry) would apply to the designated conventional cap area of 5.4 acres.

Alternative 3A2

Alternative 3A2 is similar to 3A1 except that it involves removing up to 3 feet of sediment over the area defined by the risk-drivers to the SQS footprint, placing a conventional cap over residual contamination greater than two times the SQS and performing ENR over the remaining area to the Urban AOPA footprint. Figure 11-12 illustrates the removal, capping, and ENR areas. Under this alternative, about 30 acres of subtidal sediment would be remediated and would include removal of 123,000 cubic yards of contaminated sediments. Shoreline and former shipway remediation are also included, as discussed above under Alternative 3A1. Institutional controls would include seafood consumption advisories, public outreach, and education on a sitewide basis; proprietary controls (e.g., notification of waterway users, enforcement tools, and site registry) would apply to the designated conventional cap area of 5.4 acres. This subalternative would also include removing pier structures within areas to be dredged.

11.4.3.2 Alternative 3B— Removal-Focus – Remove High Concentration Materials to CSL in Dry Dock 1 Area

This removal-focus alternative addresses the area characterized by the presence of waste materials containing some of the greatest concentrations of COCs. The dredged area footprint within Dry Dock 1 is about 4 acres. Any residuals within this area would be managed with backfill/ENR. In the remaining areas of the Site, capping/ENR footprints would be applied as appropriate, with a conventional cap being placed over sediments above the area defined by the risk drivers to the CSL and ENR applied in the remaining area to the Urban AOPA footprint. Figure 11-13 illustrates the removal area of Dry Dock 1, conventional capping within remaining CSL footprint reduced by Dry Dock 1 removal boundary, and ENR to the Urban AOPA. Removal of contaminated sediments within this area is also consistent with, and would not preclude, potential future site uses in this part of the waterway. Under this alternative, 30 acres of subtidal sediment would be remediated and would include removal of 90,000 cubic yards of contaminated sediments. Shoreline and former shipway remediation are also included, as

discussed above under Alternative 3A1. Institutional controls would include seafood consumption advisories, public outreach, and education on a sitewide basis; proprietary controls (e.g., notification of waterway users, enforcement tools, site registry) would apply to the designated conventional cap area of 6.3 acres.

11.4.3.3 Alternative 3C— Removal-Focus – Remove High Concentration Materials to CSL in Dry Dock Areas

This removal-focus alternative expands on the removal of COC contaminant mass to include the area associated with former Dry Docks 1, 2, and 3. It addresses the areas with the greatest concentrations of COCs. The dredged area footprint within the dry dock areas is about 10 acres. Any residuals within this area would be managed with backfill/ENR. In the remaining areas of the site, conventional capping would be limited to 1.3 acres and would not be needed elsewhere due to removal of high concentration materials to the CSL. ENR footprints would be based on the Urban AOPA footprint. (Figure 11-14). Focusing the removal of COCs on the former dry dock areas will address the portions of the Site where sand-blast grit and other waste materials typical of historic ship-building activities are present. Under this alternative, about 30 acres of subtidal sediment would be remediated and would include removal of 148,500 cubic yards of contaminated sediments. Shoreline and former shipway remediation are also included, as discussed above under Alternative 3A1. Institutional controls would include seafood consumption advisories, public outreach, and education on a sitewide basis. Proprietary controls, such as notification of waterway users, enforcement tools, and a site registry, would be limited and only apply to the designated conventional cap area of 1.3 acres.

11.4.4 Alternative 4— Complete Removal

This removal action alternative expands the mass removal of sediments to include areas above specific RALs across the entire remedial action area (i.e., AOPAs). This alternative represents the greatest contaminant mass removal for all COCs. The goal of this alternative would be to eliminate the contaminated sediment above specific RALs at dredged depth and the need for long-term monitoring, and O&M. Sediment dredging, disposal, and backfill activities would be similar to those described under Alternative 3. This remedy alternative is designed to address contaminant mass removal concerns and to achieve RAO 1 through a combination of active remediation and institutional controls, achieve the PRGs for RAOs 2 and 4 on a sitewide average

basis and the PRGs (i.e., SQS) for RAO 3 on a point basis immediately following construction, and be protective of human health and the environment immediately upon completion.

The components of this alternative include the following:

- Pier demolition and disposal;
- Dredging entire remedial action area above specific RALs;
- Transporting sediment via rail for disposal at a permitted upland landfill facility;
- In dredged areas, managing dredging residuals; and
- Performing former shipway area remediation and shoreline remediation/habitat restoration/improvements.

This alternative is divided into three subalternatives based on various AOPAs and RALs:

- Alternative 4A – Removal to SQS AOPA footprint (Figure 11-15)
- Alternative 4B – Removal to Urban AOPA footprint (Figure 11-16)
- Alternative 4C – Removal to the study area boundary AOPA (Figure 11-17)

11.4.4.1 Alternative 4A— Complete Removal to SQS Surface Sediment Footprint

Sediments within SQS AOPA footprint of about 18 acres where the risk-driver COCs are greater than SQS levels would be removed and disposed of to an upland disposal facility. Estimated dredge volume is about 342,000 cubic yards. Any residuals within this area would be managed with backfill. Common remedy elements of shoreline and former shipway remediation are included and add about 2 acres and removal of approximately 10,000 cubic yards. Institutional controls would include seafood consumption advisories, public outreach, and education on a sitewide basis. Institutional controls regarding long-term protection of a capping system and future site use restrictions would not apply. No long-term O&M monitoring would be implemented specific to the Site. The status of seafood consumption advisories will be assessed through regional monitoring activities.

11.4.4.2 Alternative 4B— Complete Removal to Urban Surface Sediment Footprint

Sediments within Urban AOPA footprint of about 30 acres where the risk-driver COCs are greater than Urban levels would be removed and disposed of to an upland disposal facility. Estimated dredge volume is about 802,500 cubic yards. Any residuals within this area would be

managed with backfill. Common remedy elements of shoreline and former shipway remediation are included and add about 2 acres and removal of approximately 10,000 cubic yards. The institutional controls would include sitewide seafood consumption advisories, public outreach, and education but would not include institutional controls regarding long-term protection of a capping system and future Site use restrictions. No long-term O&M monitoring would be implemented specific to the Site. The status of seafood consumption advisories will be assessed through regional monitoring activities.

11.4.4.3 Alternative 4C— Complete Removal to Study Area Boundary Surface Sediment Footprint

Sediments within the study area boundary of about 40 acres where the risk-driver COCs are greater than RBTC/natural background levels would be removed and disposed of to an upland disposal facility. Estimated dredge volume is about 1,214,300 cubic yards. Any residuals within this area would be managed with backfill. Common remedy elements of shoreline and former shipway remediation are included and add about 2 acres and removal of approximately 10,000 cubic yards. All RAOs are expected to be achieved. No institutional controls or long-term O&M monitoring would be implemented.

Table 11-1.
Remedial Action Levels for the Risk-Driver Contaminants of Concern

Risk Driver	Basis	Remedial Action Levels			
		CSL	SQS	Urban	RBTC/NBkgd
cPAHs	µg/kg-dw	3,000	1,100	757	9
Arsenic	mg/kg-dw	93	57	84	7
Lead	mg/kg-dw	530	450	47	11
Copper	mg/kg-dw	390	390	49	114
Mercury	mg/kg-dw	0.59	0.41	0.44	0.41
TBT	µg/kg-dw	1,335	1,335	N/A	150
	mg/kg-OC	78	78	N/A	N/A
Total PCBs	µg/kg-dw	1,000	180	119	2
	mg/kg-OC	65	12	n/a	n/a

Notes:
µg/kg = microgram per kilogram
cPAHs = carcinogenic polycyclic aromatic hydrocarbons
CSL = Cleanup Screening Level
mg/kg-dw= milligram per kilogram dry weight
mg/kg-OC = milligram per kilogram organic carbon
N/A = not applicable
NBkgd = Natural Background
PCBS = polychlorinated biphenyls
RBTC = Risk-Based Threshold Concentration
SQS = Sediment Quality Standard
TBT = tributyltin

Table 11-2. Remedial Alternatives and Associated Remedial Technologies, Remedial Action Levels, Actively Remediated Areas, and Volumes.

Remedial Alternatives and Technologies[1/]	Brief Description and Expected Outcomes	RAL Basis	Remedial Action Levels Lockheed West Risk Drivers Total PCBs (µg/kg dw)[2/]	cPAHs (ug TEQ/kg dw)[3/]	Arsenic (mg/kg dw)	Copper (mg/kg dw)	Lead (mg/kg dw)	Mercury (mg/kg dw)	Tributyltin (ug/kg dw)[4/]	Dioxins/Furans (ngTEQ/kg dw)[5/]	Benthic SMS (41 Chemicals)	Actively Remediated Areas (Acres)[8/]; Removal Volumes (cy)
Alternative 1 - No Action	CERCLA baseline alternative used for comparison to other alternatives.		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
Alternative 2 - Containment-Focus	This alternative focuses on containment (capping/ENR). Common elements for this alternative include removal of debris in all areas that would prohibit cap placement /effectiveness, installing a 3-ft cap in high concentration areas /ENR (6-in sand layer) in low concentration areas [6/] to a specific surface sediment RAL footprint; leaving pier structures in place, enhance intertidal habitat, and Institutional Controls/Restrictive covenants on site use to protect cap.											
Alternative 2A (2A1, 2A2a, 2A2b, 2A3, 2A4a, 2A4b, and 2A4c)	Cap/ENR surface sediments based on varying AOPA footprints (e.g., SQS, Urban, Study area boundary)	SQS (2A1, 2A4a)	180	1,100	57	390	450	0.41	1,335	n/a	SQS	18 acres
		Urban (2A2a, 2A2b, 2A4b)	119	757	8	49	47			n/a	SQS	30 acres
		RBTC/Nat.Bkd (2A3/2A4c)	n/a[7/]	n/a[7/]	7	114	11		150	n/a	SQS	40 acres
Alternative 2B - Containment Focus with Removal – minimize changes to water depth.	Similar to Alt 2A3, cap/ENR surface sediments based on study area boundary AOPA footprint but includes removal of sediments to minimize changes to water depths. This subalternative would also include removing pier structures within areas to be dredged to fit cap, if necessary.	RBTC/Nat.Bkd (2B)	n/a[7/]	n/a[7/]	7	114	11	0.41	150	n/a	SQS	40 acres Removal = 51,800 cy
Alternative 3 - Removal-Focus	This alternative focuses on removing high concentration materials in surface sediments then capping/ENR the removal area and the remainder of the Site. Common elements for this alternative include dredging high concentration sediment areas, disposing of dredged sediment at upland disposal facility, removing pier structures within the dredge areas, removing debris in all areas that would prohibit cap placement /effectiveness, 3-ft capping in remaining high concentration areas /ENR (6-in sand layer) low concentration areas [6/] containing exceedances of a specific RAL, enhancing intertidal habitat, Institutional Controls/Restrictive covenants on site use to protect cap.											
Alternative 3A – Removal Focus – remove 3 feet over CSL (3A1) or SQS (3A2) surface sediment footprint.	This combined removal and containment alternative is included to address mass removal of the most impacted sediments and is not bounded by former operational areas. The dredged area would be capped/ENR along with other areas to the Urban AOPA footprint.	3A1 - CSL	1,000	3,000	93	390	530	0.59		n/a	SQS	30 acres Removal = 55,500 cy
		3A2 - SQS	180	1,100	57	390	450	0.41	1335			30 acres Removal = 123,000 cy
Alternative 3B – Removal Focus – remove high concentration materials to CSL in Dry Dock 1 area.	This combined removal and containment alternative addresses the area with the greatest concentrations of COCs. The dredged area would be capped/ENR along with other areas to the Urban AOPA footprint. Removal of contaminated sediments within this area is also consistent with and would not preclude, potential future site uses in this part of the waterway.	CSL	1000	3000	93	390	530	0.59	1335	n/a	SQS	30 acres Removal = 90,000 cy
Alternative 3C– Removal Focus – remove high concentration materials to CSL in Dry Dock areas.	This combined removal and containment alternative expands on the removal of COCs to include the area associated with former Dry Docks #1, 2, and 3. It addresses the areas with the greatest concentrations of COCs. The dredged area would be capped/ENR along with other areas to the Urban AOPA footprint. Focusing the removal of COCs on the former dry dock areas will address the portions of the site where sand-blast grit and other waste materials typical of historic ship building activities are present.	CSL	1000	3000	93	390	530	0.59	1335	n/a	SQS	30 acres Removal = 148,500 cy
Alternative 4 - Removal	This alternative is based solely on removal; no capping would be implemented in areas within the removal area or outside the removal area footprint. Common elements include removal of pier structures within the dredge areas, dredging sediments exceeding RAL criteria, disposing of dredged sediment at upland disposal facility, managing dredge residuals as necessary, and enhancing intertidal habitat.										SQS	
Alternative 4A – SQS AOPA	Removal to the SQS footprint.	SQS	180	1,000	57	390	450	0.41	1,335	n/a	SQS	18 acres Removal = 342,000 cy
Alternative 4B – Anthropogenic (Urban) AOPA	Removal to the Urban footprint.	Urban	119	757	8	49	47	0.41	1,335	n/a	SQS	30 acres Removal = 802,500 cy
Alternative 4C – Study Area Boundary AOPA	Removal to the Study Area Boundary	RBTC/Nat.Bkd.	n/a[7/]	n/a[7/]	7	114	11	0.41	150	n/a	SQS	40 acres Removal = 1,214,300 cy

Notes:
1/ Alternatives 2 through 4 include shoreline remediation/enhancement, limited removal and capping of the former Shipway area, institutional controls (where applicable).
2/ Total PCBs concentrations of 1,000 ug/kg dw and 180 ug/kg dw are dry weight approximations of the 65 mg/kg oc (CSL) and 12 mg/kg oc (SQS) values assuming 1.5 percent organic carbon. Compliance with SMS (RAO 3) will be evauated using oc-normalized data as approriate.
3/ RALs for cPAHs are based on LAET and 2LAET dry weight approximations of the SQS and CSL values for benzo(a)pyrene. Individual cPAH compounds are also incorporated in SMS (RAO 3).
4/ SQS value for tributyltin is the West Waterway Confirmational Number
5/ Dioxins/Furans are identified as risk-drivers but because no sediment data for Lockheed West are available, no RALs were developed for the FS. Remediation of other risk-driver COCs is expected to address potential risks from dioxins/furans.
6/ For containment RAL footprint: Conventional cap is assumed for areas > 2xSQS and ENR is assumed for areas < 2xSQS.
7/ RBTCs or the 95 UCL from the "Bold Study" for Total PCBs and cPAHs are significantly below the Elliott Bay-wide sediment concentrations and could not be used to define a study area boundary.
8/ In addition to what is shown in the table, actively remediated areas include additional 2 acres of former shipway remediation, shoreline/intertidal improvements and removal of approximately 10,000 cubic yards.

AOPA = area of potential action; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; cy = cubic yard; dw = dry weight; ENR = enhanced natural recovery; LAET/2LAET = lowest apparent effect threshold; mg/kg = milligrams per kilogram; n/a = nat applicable; Nat. Bkd. = natural background = values are the 95 UCL on the mean data compiled in the "Bold Study" (DMMP 2009); ng TEQ/kg = nanograms toxicity equivalents per kilogram; oc = organic carbon; PCB = polychlorinated biphenyl; RAL = remedial action level; RAO = remedial action objective; RBTC = risk-based threshold concentration; SMS = sediment management standards; SQS = sediment quality standard; TBD = to be determined; TEQ = toxic equivalent; TOC = total organic carbon; UCL = upper confidence limit; µg/kg = micrograms per kilogram; Urban = Anthropogenic background

Table 11-3.
Technology Applicability Assumptions for the Feasibility Study

Technology [1/]	Sediment Chemical Concentration [2/]	Physical Conditions (Shipway Area, Shoreline, Slope Stability)	Elevation Requirements (Habitat, Navigation Channel) [3/]
Removal	No upper concentration limit. Vertical extent is to the depth of RAL exceedances. A 50% volume adjustment factor is added to the neat volume for Alternatives 2 through 4. Post-dredge residuals management in all dredge areas with 6 inches of thin-layer sand placement.	Removal Alternatives: partially viable in former shipway area. In this area, assume partial dredging and capping. Applicable in all other areas.	Habitat areas: (i.e., elevations > -10 ft MLLW), assume backfill to grade to maintain habitat. No restrictions in navigation channel.
Partial Dredging and Capping	No upper concentration limit. Dredge vertically to the depth necessary to fit a 3-ft cap and comply with post-construction elevation assumptions.	Applicable in all areas. Engineered capping as necessary in shipway areas and in shoreline/intertidal remediation areas including slopes greater than 1v:3h. Partial dredging and capping is the default active technology for the former shipway area and in shoreline remediation area applicable to all alternatives.	Habitat areas: partial dredge 3 ft and sand cap to grade. Finish with habitat suitable substrate. Navigation channel: partial dredge to provide 4 ft clearance between the top of the cap and the deepest permitted maintenance depth.
Capping	No upper concentration limit.	Applicable in all areas. Engineered capping as necessary in former shipway area, shoreline/intertidal remediation area and in capping areas where the slopes are greater than 1v:3h. Capping is the default active technology for the combined-technology alternatives.	Habitat areas: partial dredge and cap (see above). Navigation channel: Applicable in areas with 4 ft clearance between the top of the cap and the deepest permitted maintenance depth.
ENR	Upper limit for ENR is <2 x SQS for all alternatives, and for human health risk drivers in the intertidal areas.	Applicable to all areas of the Lockheed West Site.	ENR is viable in both habitat and navigation areas.
Institutional Controls and Site-Wide Monitoring [4/]	Apply to all areas of Lockheed West.	Apply to all areas of the Lockheed West Site.	Apply to all areas of the Lockheed West Site.

Notes:
1/ Criteria and assumptions are for the FS and may be changed during remedial design.
2/ Sediment concentration in the upper 10 cm is compared to alternative specific RALs throughout the site. In intertidal areas, the RALs for human health risk drivers are compared to both surface sediment and to the vertical average of the upper 45 cm in intertidal areas.
3/ Habitat areas are defined as nearshore areas with bathymetric elevations greater than -10 ft MLLW. Navigational channel areas (e.g., West Waterway) have water depth requirements to ensure safe passage of vessels.
4/ Institutional controls in the form of seafood consumption advisories apply sitewide for all alternatives. Ranges of institutional controls and monitoring apply to specific actions and areas, such as areas where buried contamination is contained on site. Sitewide monitoring will assess long-term progress toward the remedial action objectives for all alternatives.
ENR = enhanced natural recovery; MLLW = mean lower low water; RAL = remedial action level; RAO = remedial action objective; SQS = Sediment Quality Standard

Table 11-4.
Area-Specific Volume and Construction Assumptions for Development of Feasibility Study Remedial Costs

Elevation or Geographic Limits [1/]	Applicable Active Remedial Technologies [2/]	Volume Estimating Assumptions and Construction Assumptions
MHHW to -10 ft MLLW	Excavate using land-based or barge-mounted excavator, backfill, ENR	For cost estimating, excavation, backfilling, and ENR are performed by barge-mounted precision excavator. Dredged surface is restored to approximate pre-dredge bathymetry [3/]. Dredging will therefore be followed by backfilling with sand to approximate pre-existing grades. Areas are assumed to be partially dredged to 3 ft below mudline, performed at current stable slope and backfilled to grade with sand habitat substrate. Riprap armoring is assumed to be placed over cap (see Figure 11-2). During design, additional engineering considerations in native or eroding bank areas could include the use of land-based excavation and placement. During design, additional options for improving habitat may be considered. .
Former Shipway Area	Partial dredge using specialty dredge, precision excavator from barge, or vacuum truck operation, and cap	For cost estimating purposes, partial dredging and capping is assigned in the former shipway area. Removal is assumed to be 0.5 ft and capping is assumed to be 3 ft after partial removal. Removal would occur by a method higher in cost than open water dredging.
Below -10 ft MLLW	Dredge or partial dredge and cap, ENR	For cost estimating purposes, removal and placement are performed via barge-mounted precision excavator or dredge. All cut slopes will likely need a riprap toe during construction of conventional cap along the slopes. Armoring requirements will be determined on a site-specific basis in the design phase. Active remediation adjacent to the navigation channel is assumed to account for USACE maintenance dredge tolerance and sloping from the navigation channel. During design, additional considerations include the use of capping materials other than sand, and additional elevation considerations in the navigation channel.
Additional sitewide assumptions	Removal	For cost estimating purposes, 9-inch layer of sand placed in all dredge areas to manage residuals to achieve a minimum 6-inch coverage. Removal volume equals the neat volume to >RAL, plus 50% volume that accounts for over-dredge, side slopes, box cuts (i.e., design of constructible dredge prisms), and additional characterization, and more removal in intertidal areas for Alternatives 2 through 4. See Appendix F for details of cost estimates.
	Capping/ENR	For cost estimating purposes, 3.5 ft of capping material is assumed to achieve a goal of a minimum 3-ft cap, and 12 inches of sand is assumed to achieve a 6-in ENR layer. Debris sweep is assumed for all capping and ENR areas and the cost of debris removal is incorporated into unit rate of dredge and capping. Cap and ENR maintenance is included on a cost-per-acre basis. See Appendix F for detailed cost estimates.

Notes:
1/ Intertidal and habitat range is assumed to extend from -10 ft MLLW to the approximate MHHW elevation.
2/ The process options listed in this table are primary options with sitewide applicability. Other options discussed in Section 10.7 may also be appropriate, as determined during remedial design.
3/ Backfill and restoration to original grade are assumed for all removal actions between MHHW and -10 ft MLLW. ENR does not require restoration to original grade.
ENR = enhanced natural recovery; FS = feasibility study; MHHW = mean higher high water; MLLW = mean lower low water; RAL = remedial action level; USACE = U.S. Army Corps of Engineers.

Table 11-5. Remedial Alternatives Actively Remediated Area, Volumes, Mass Removal, and Cost Summary

Remedial Alternatives		Removal Basis	Removal Area (Acres)	Cap Basis	Dredge Volume (cy) (Neat Volume)[1/]	Cap Area (Acres)	ENR/Dredge Residual Area (Acres)	Cap, ENR, Dredge Backfill Material Volume (cy)[2/]	Total Contaminant Mass Removed (MT)[3/]	Individual Contaminant Mass Removed (MT)							Cost Estimate (MM$)		
										Arsenic	Copper	Lead	Mercury	Total PCBs	cPAHs	TBT	Capital [4/]	ICs and OM&M	Total Cost
No Action	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Containment-Focus	2A1	n/a	n/a	>SQS	9,950	10.3	7.7	70,700	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	11.0	6.0	17.0
	2A2a	n/a	n/a	> Urban	9,950	10.3	19.7	90,000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	12.7	6.1	18.7
	2A2b	n/a	n/a	> Urban	9,950	18	12	121,100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	15.8	9.2	25.0
	2A3	n/a	n/a	> Bold/RBTC	9,950	10.3	29.7	106,200	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	14.1	6.1	20.2
	2A4a	n/a	n/a	> SQS	9,950	18	0	101,700	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	14.0	8.4	22.4
	2A4b	n/a	n/a	> Urban	9,950	30	0	169,400	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20.3	13.7	34.1
	2A4c	n/a	n/a	> Bold/RBTC	9,950	40	0	225,900	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	25.7	18.1	43.8
	2B	Remove to fit 3-ft cap	To meet post cap target elevation	> Bold/RBTC	44,450	10.3	29.7	106,200	24.1	1.4	16.2	6.4	0.022	0.023	0.029	0.017	27.4	5.8	33.3
Removal-Focus	3A1	Remove 3-ft >CSL footprint	10.3 (>CSL footprint)	> Urban	46,950	5.4	30	68,300	38.3	3.1	23.4	11.6	0.047	0.048	0.069	0.043	24.8	4.1	28.9
	3A2	Remove 3-ft >SQS footprint	18 (>SQS footprint)	> Urban	91,950	5.4	30	65,200	50.6	4.4	30.4	15.5	0.055	0.061	0.091	0.049	43.4	4.0	47.5
	3B	> CSL	4 (Dry Dock 1)	> Urban	69,950	6.3	23.7	72,300	59.7	3.9	35.6	19.9	0.065	0.077	0.100	0.045	33.0	4.4	37.5
	3C	> CSL	10.3 (Dry Dock 1, 2, 3)	> Urban	108,950	1.3	28.7	49,600	91.0	6.5	56.5	27.6	0.113	0.112	0.146	0.071	44.5	2.4	47.0
Complete Removal	4A	>SQS	23	n/a	237,950	0	18	21,800	136.9	11.4	83.2	41.7	0.159	0.137	0.220	0.087	92.0	0.3	92.3
	4B	> Urban	34	n/a	544,950	0	30	36,300	181.2	17.9	108.6	54.0	0.193	0.155	0.290	0.091	203.8	0.3	204.0
	4C	> Bold/RBTC	40	n/a	819,450	0	40	48,400	194.9	19.6	117.5	57.0	0.220	0.159	0.310	0.090	302.8	0.0	302.8

Notes:

1/ Neat dredge volumes were estimated by utilizing C-Tech MVS 3-D Model and AuoCAD/Civil3D. Total contaminat mass were calculated using the neat dredge volume. For FS costing purpose, neat dredge volume was increased by 50% to account for the various causes of volume creep.

2/ Cap volume was estimated using 3.5 ft layer of sand over cap footprint to reach minimum 3 ft coverage. ENR volume was estimated using 12 inch layer of sand over ENR footprint to reach minimum 6 inch coverage. Dredge backfill volume was estimated using 9 inch layer of sand over dredge footprint to reach minimum 6 inch coverage.

3/ Total contaminant mass removed is the sum of the individual contaminant mass removed. The contaminant mass removed estimates were determined from the C-Tech MVS 3-D model using the average concentration for the contaminants within the estimated sediment volume for the removal basis.

4/ Includes total direct and indirect costs (labor, equipment, material costs and contingencies). See Appendix F for detailed cost estimates.

Bold = natural background (i.e., values are the 95 UCL on the mean data compiled in the "Bold Study" [DMMP 2009]); cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; cy = cubic yards; dw = dry weight; ENR = enhanced natural recovery; MT = metric tons; n/a = not applicable; oc = organic carbon; PCB = polychlorinated biphenyl; RAL = remedial action level; RAO = remedial action objective; RBTC = risk-based threshold concentation; SMS = sediment management standards; SQS = sediment quality standard; UCL = upper confidence limit; Urban = Anthropogenic background value is 95 UCL on the mean data reported in Ecology (2008) for the "urban" stations

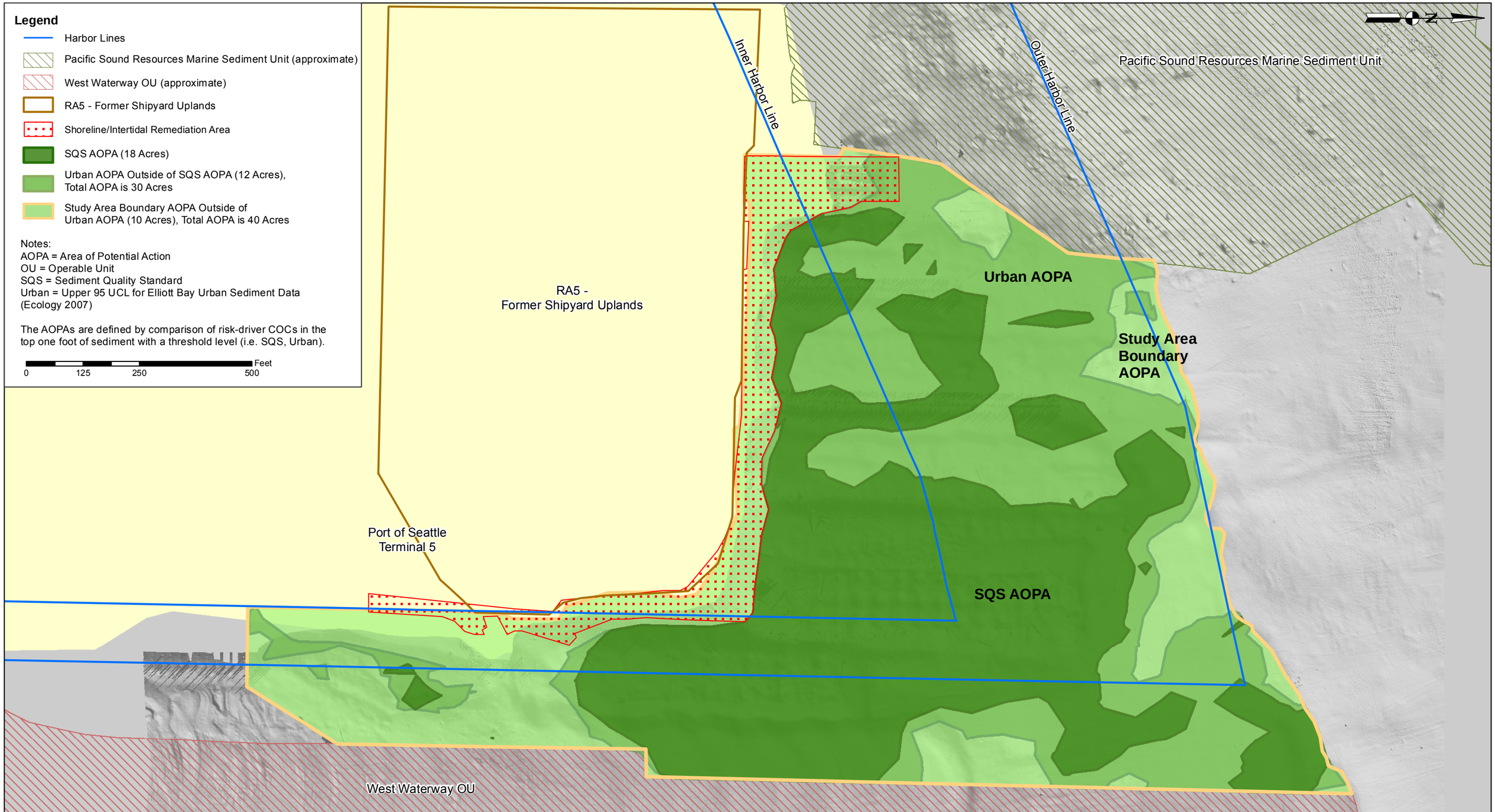


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Figure 11-1
Areas of Potential Action

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Figure 11-2
Former Shipway Area and Shoreline/Intertidal Remediation

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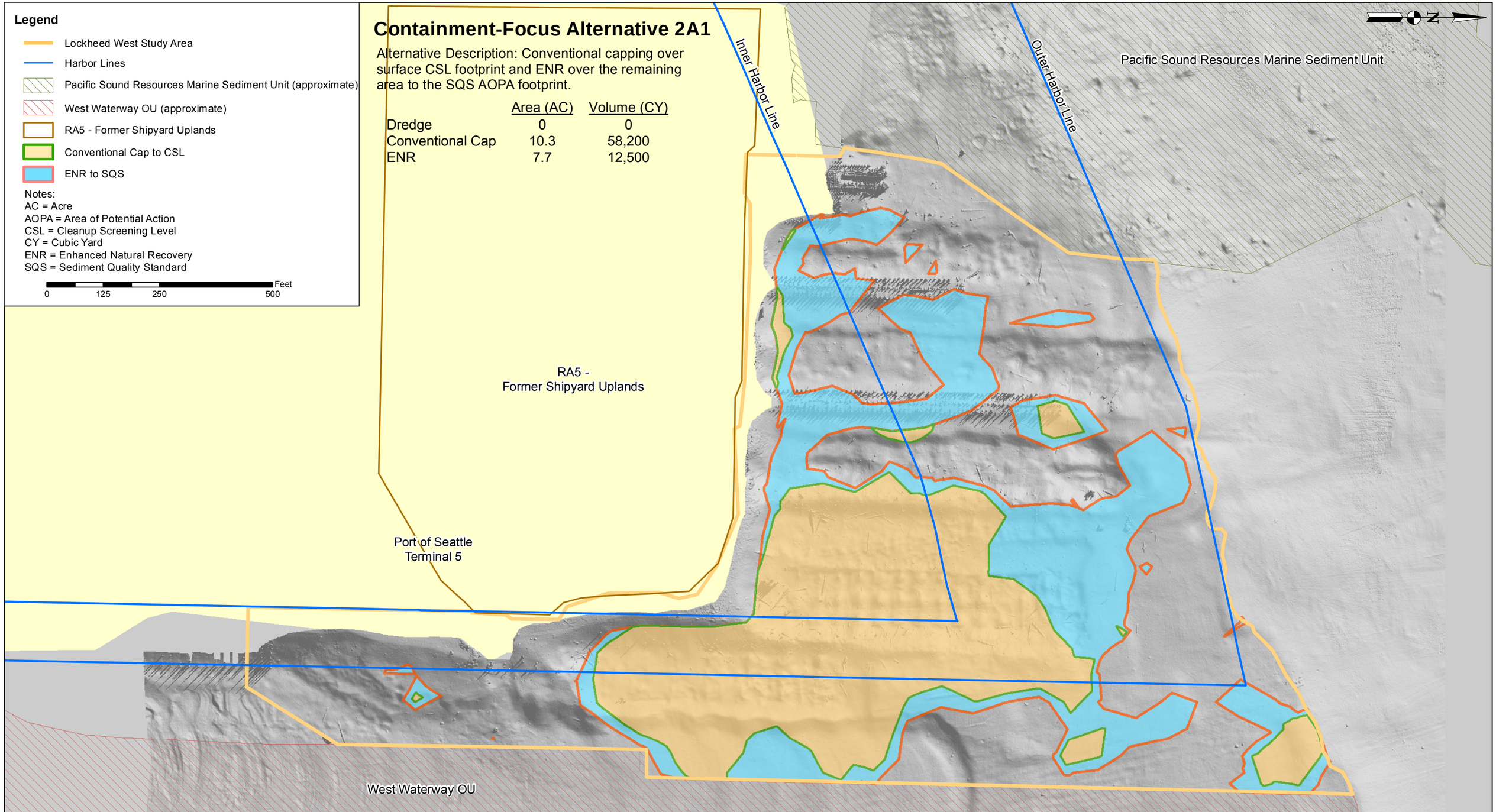

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Figure 11-3
Containment-Focus Alternative 2A1

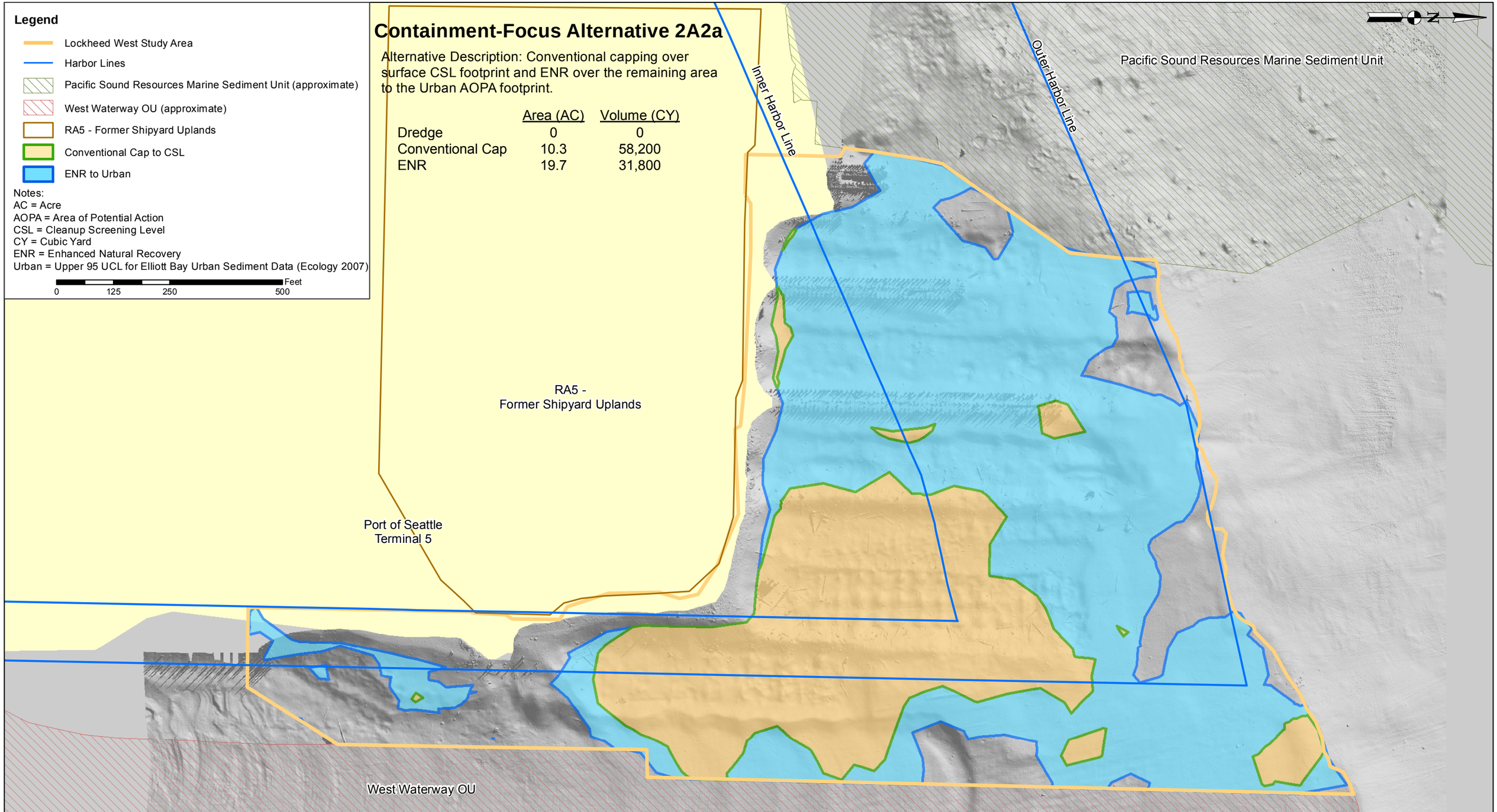

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Figure 11-4
Containment-Focus Alternative 2A2a

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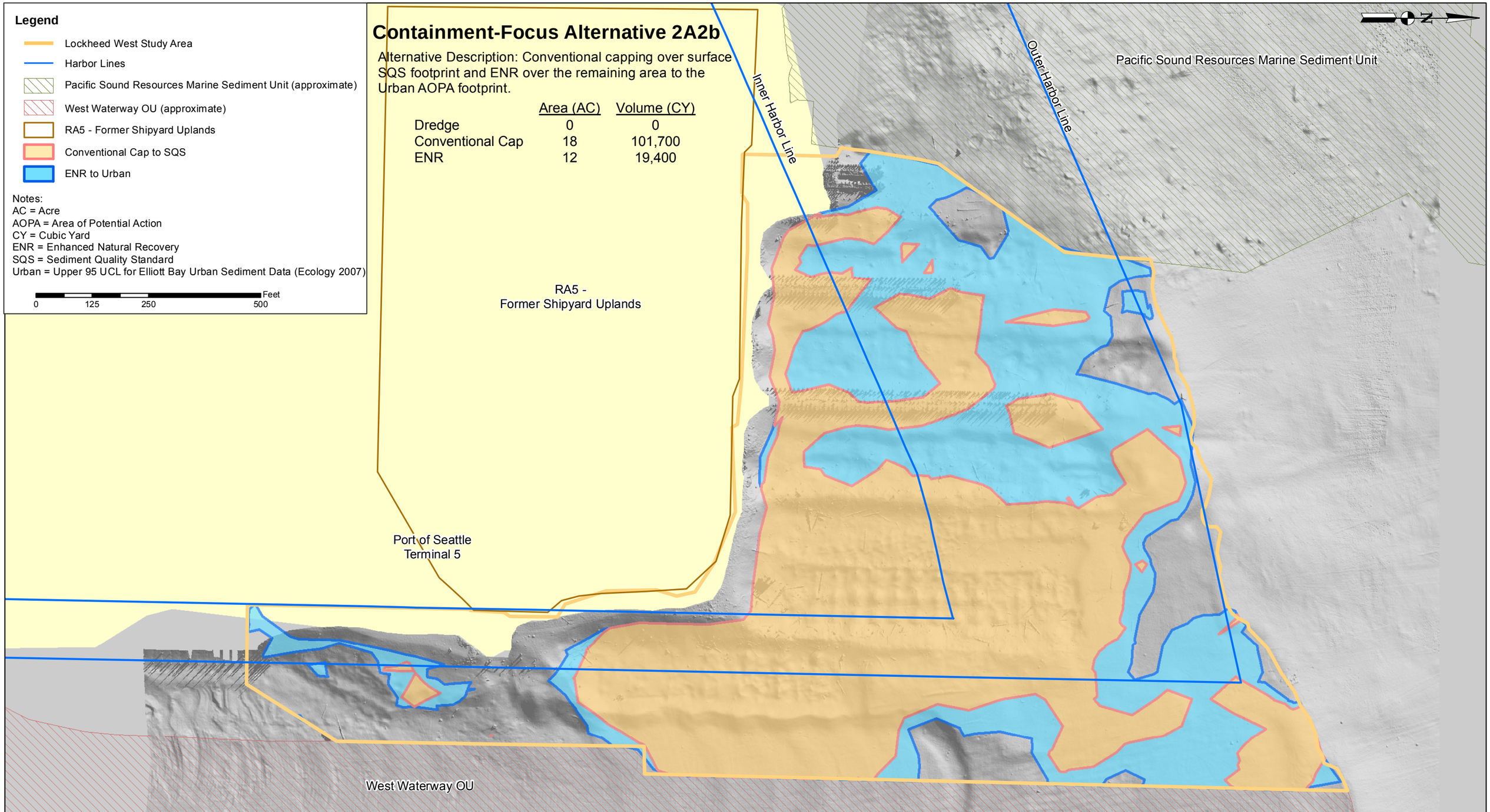

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Figure 11-5
Containment-Focus Alternative 2A2b

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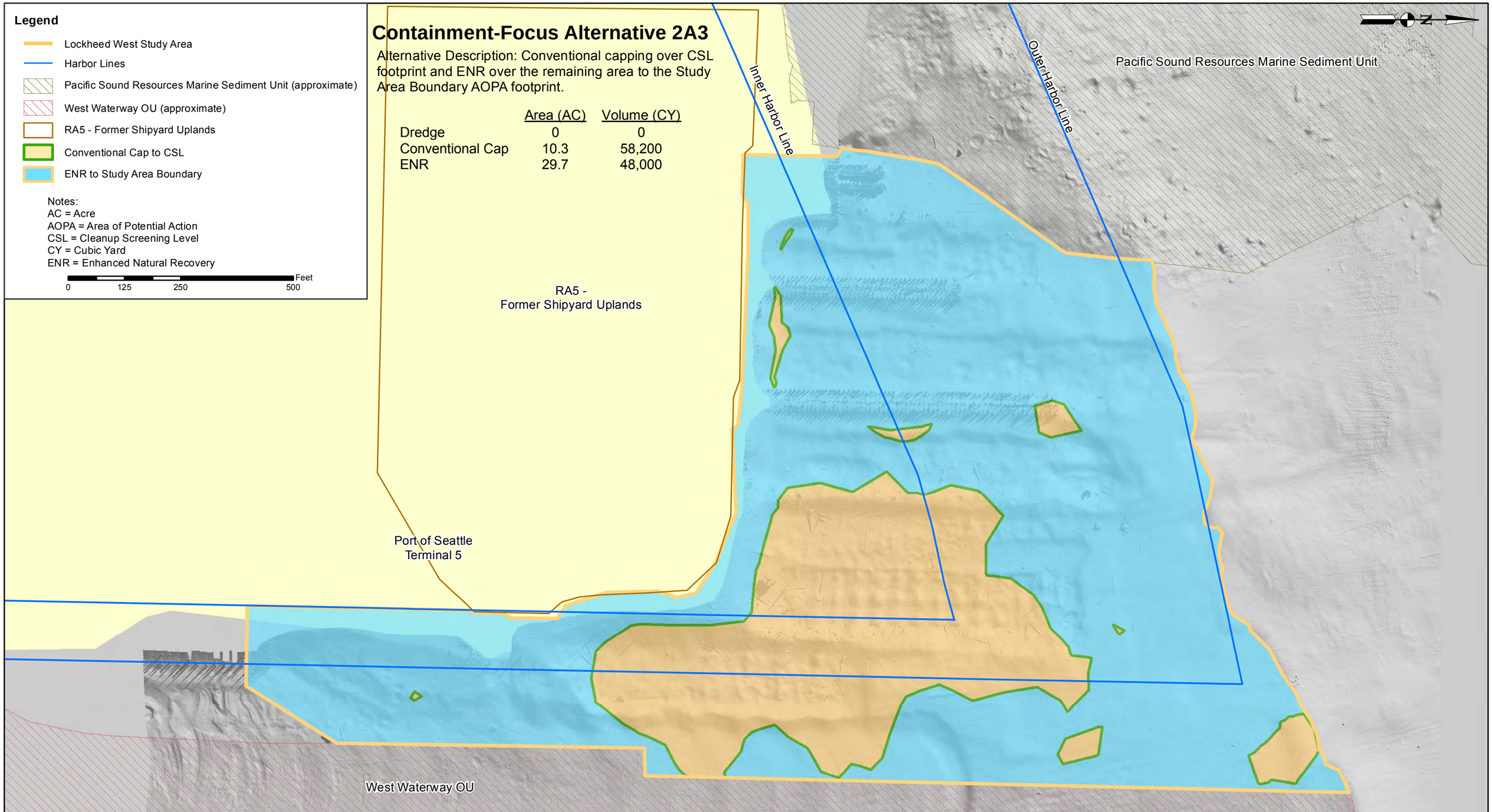

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Figure 11-6
Containment-Focus Alternative 2A3

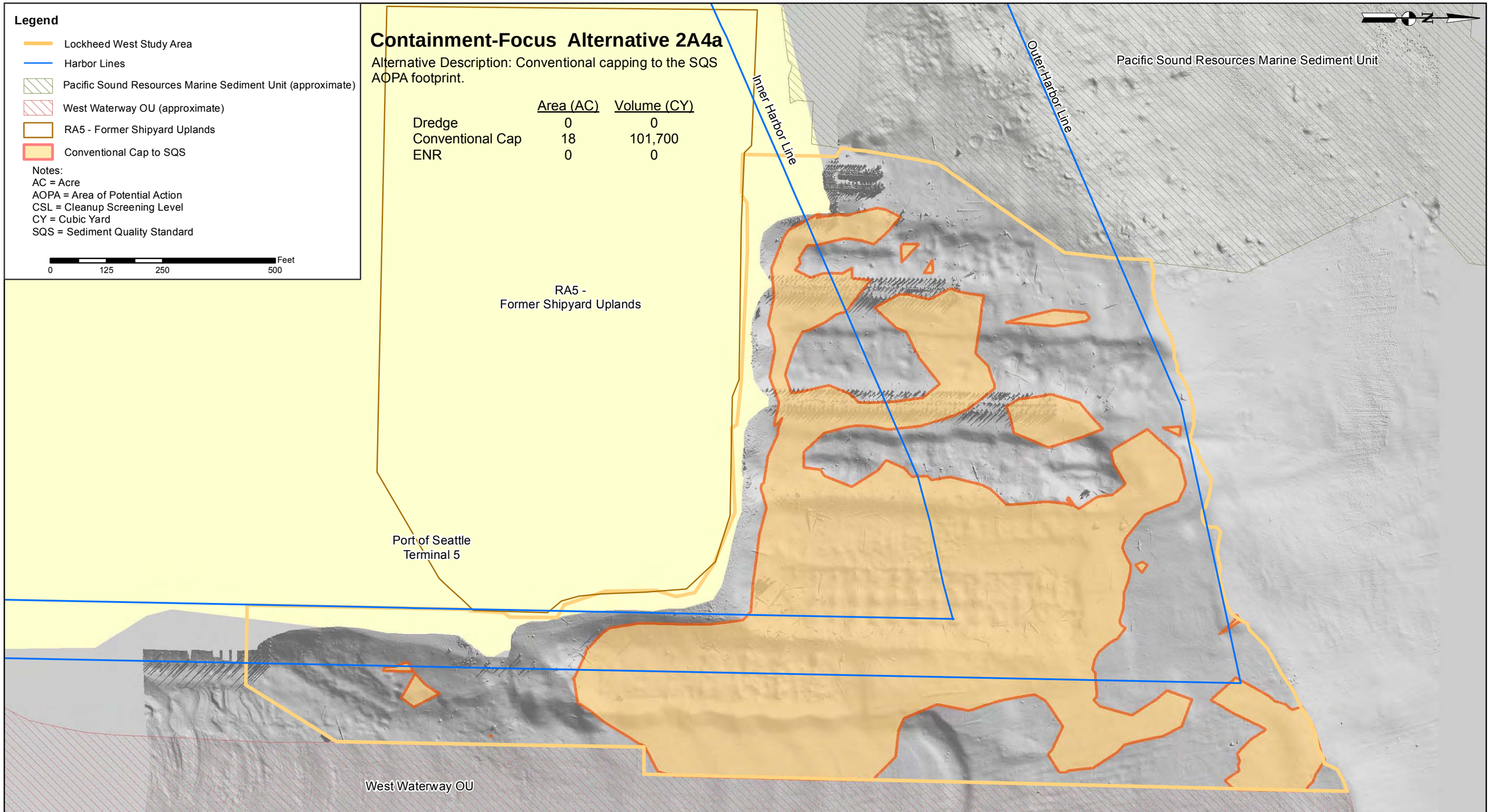

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Figure 11-7
Containment-Focus Alternative 2A4a

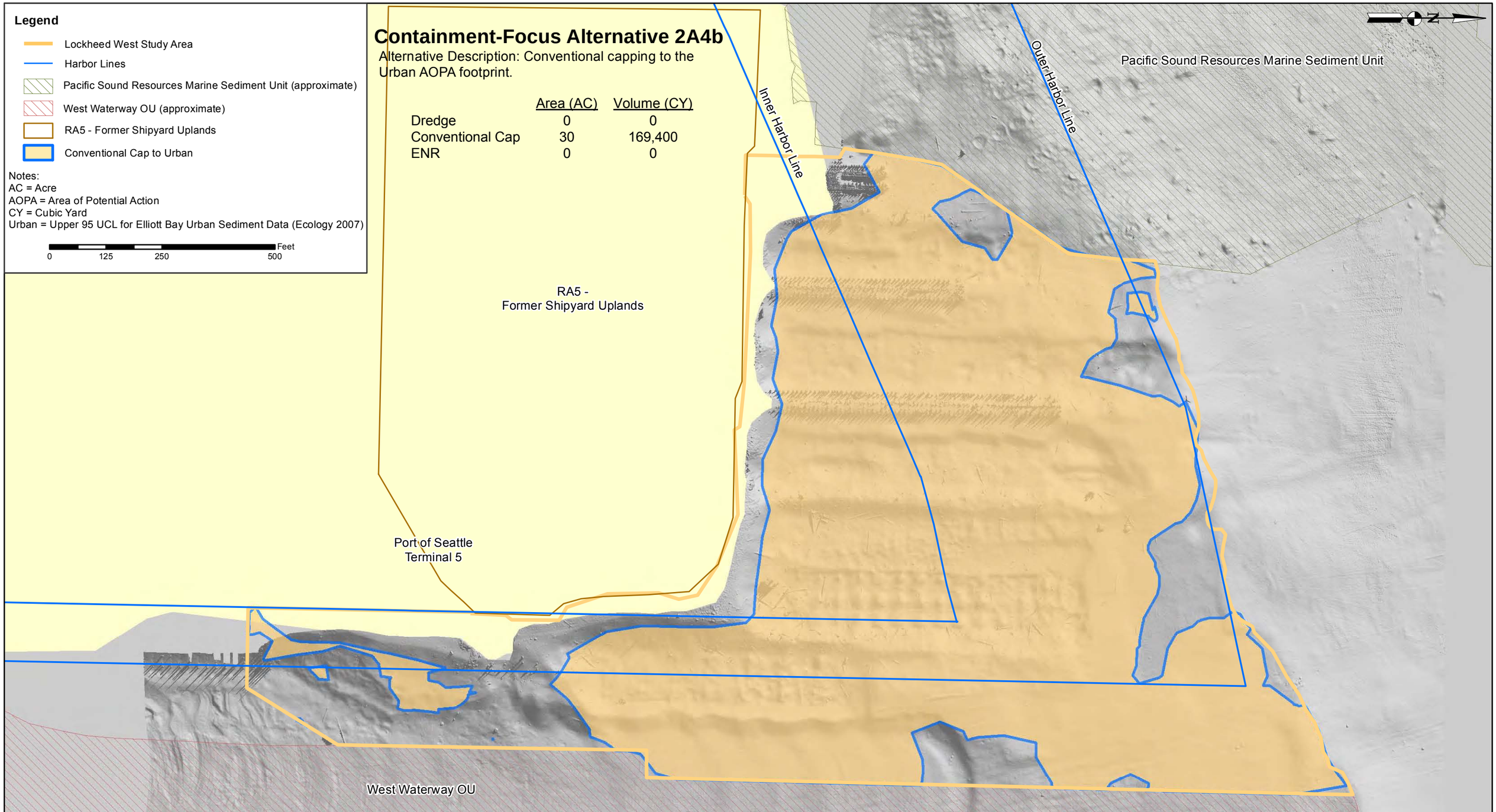

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Figure 11-8
Containment-Focus Alternative 2A4b

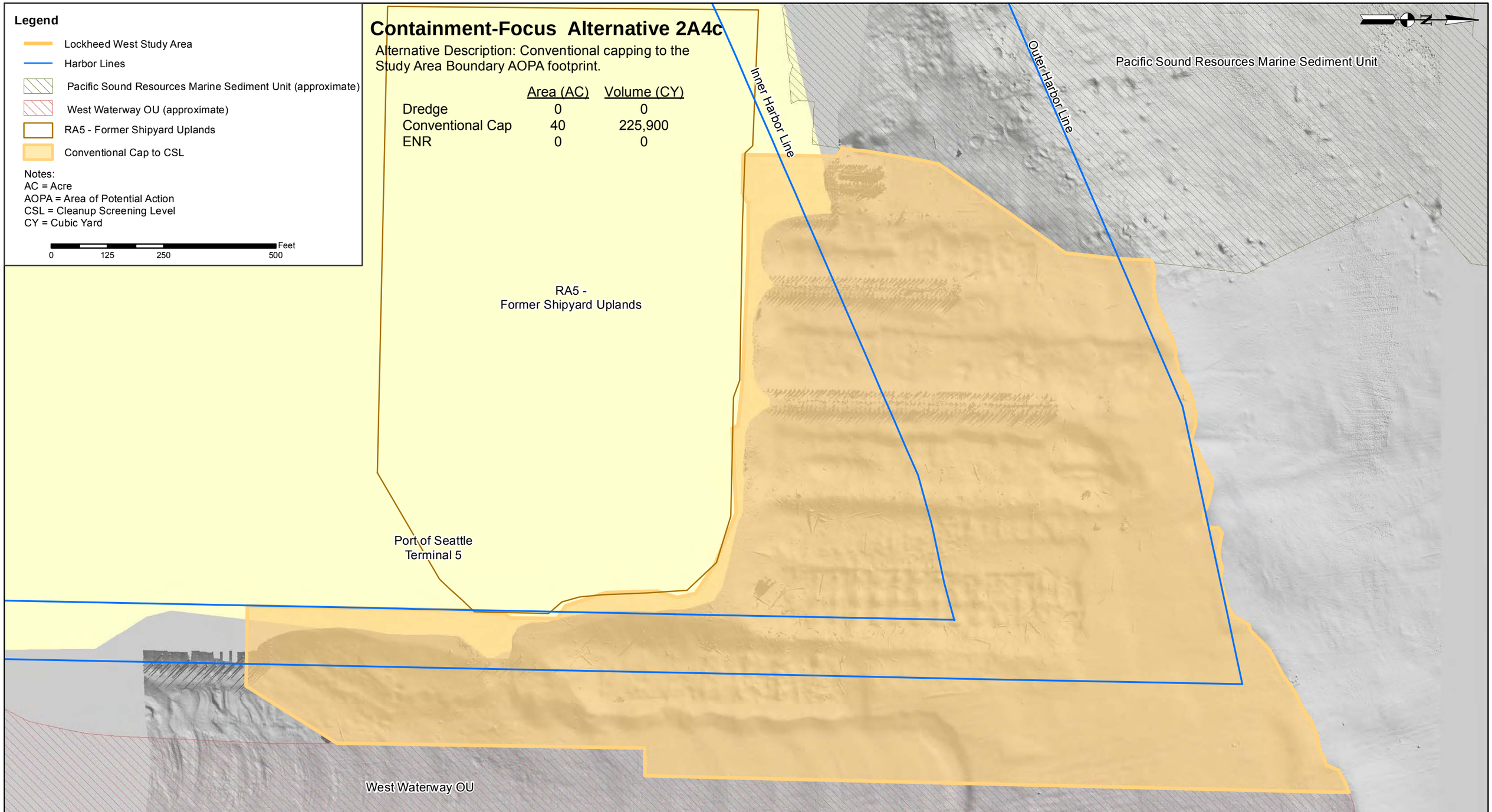

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Figure 11-9
Containment-Focus Alternative 2A4c

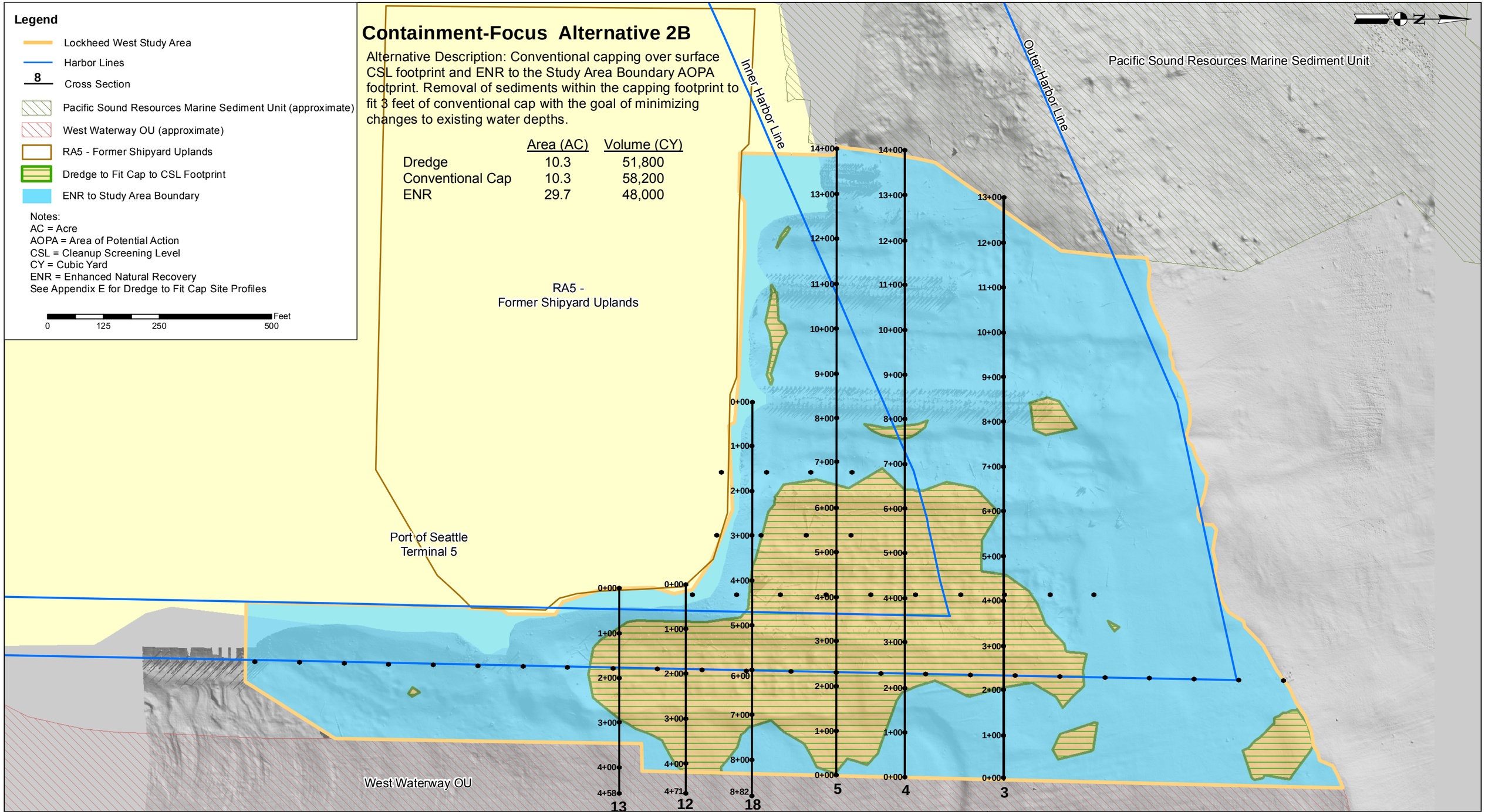

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Figure 11-10 Containment-Focus Alternative 2B

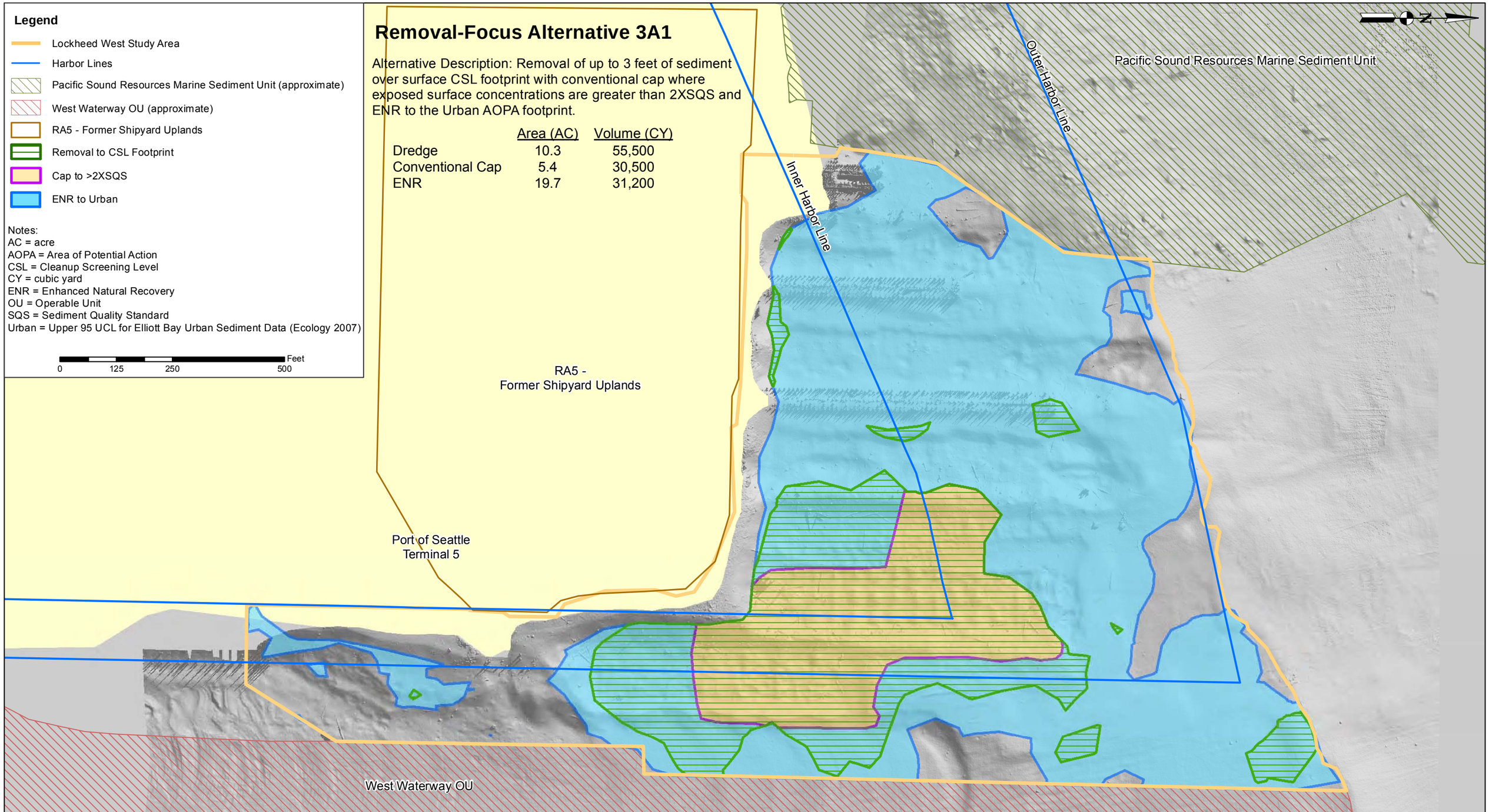

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Figure 11-11
Removal-Focus Alternative 3A1

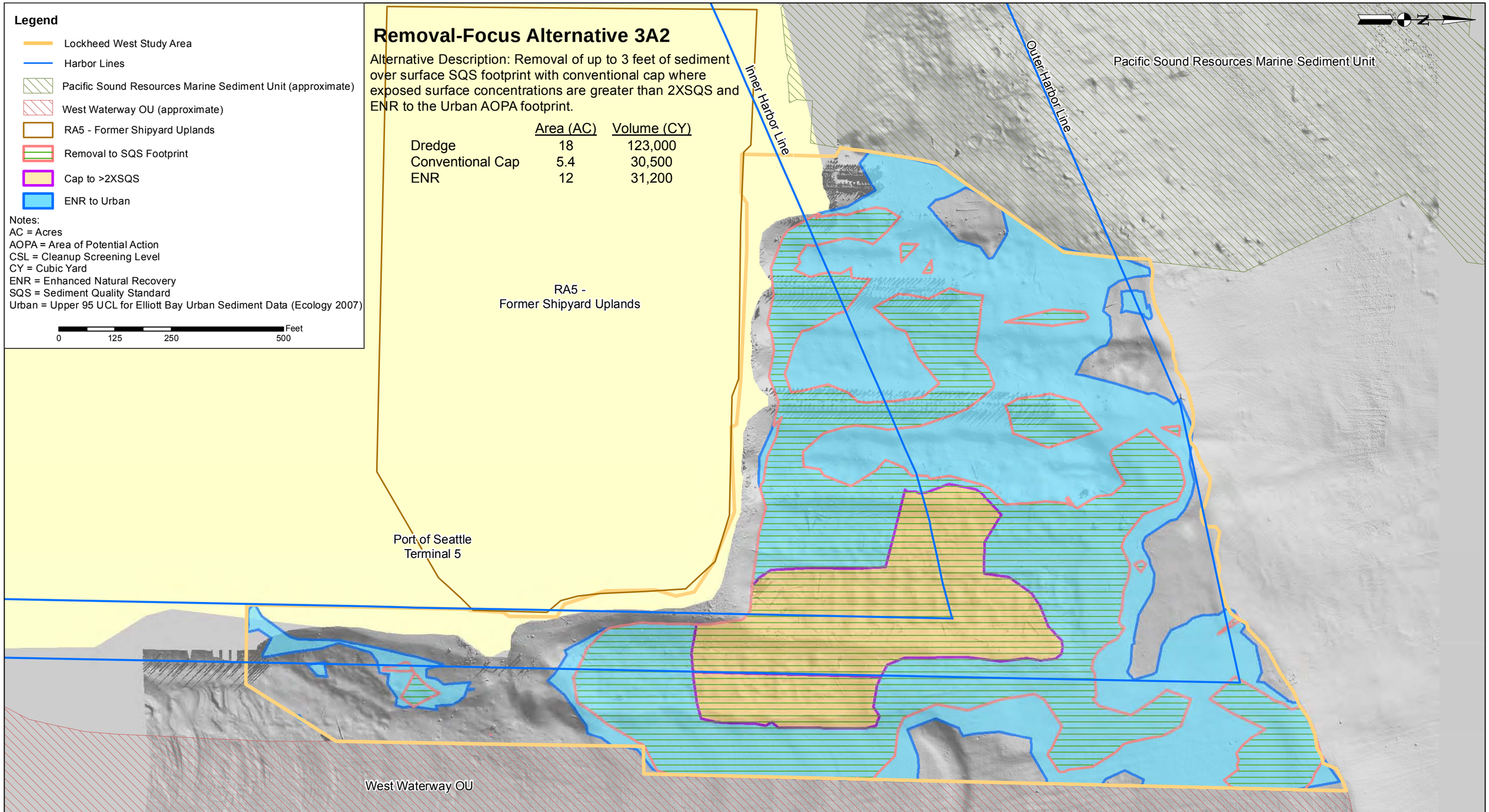

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Figure 11-12
Removal-Focus Alternative 3A2

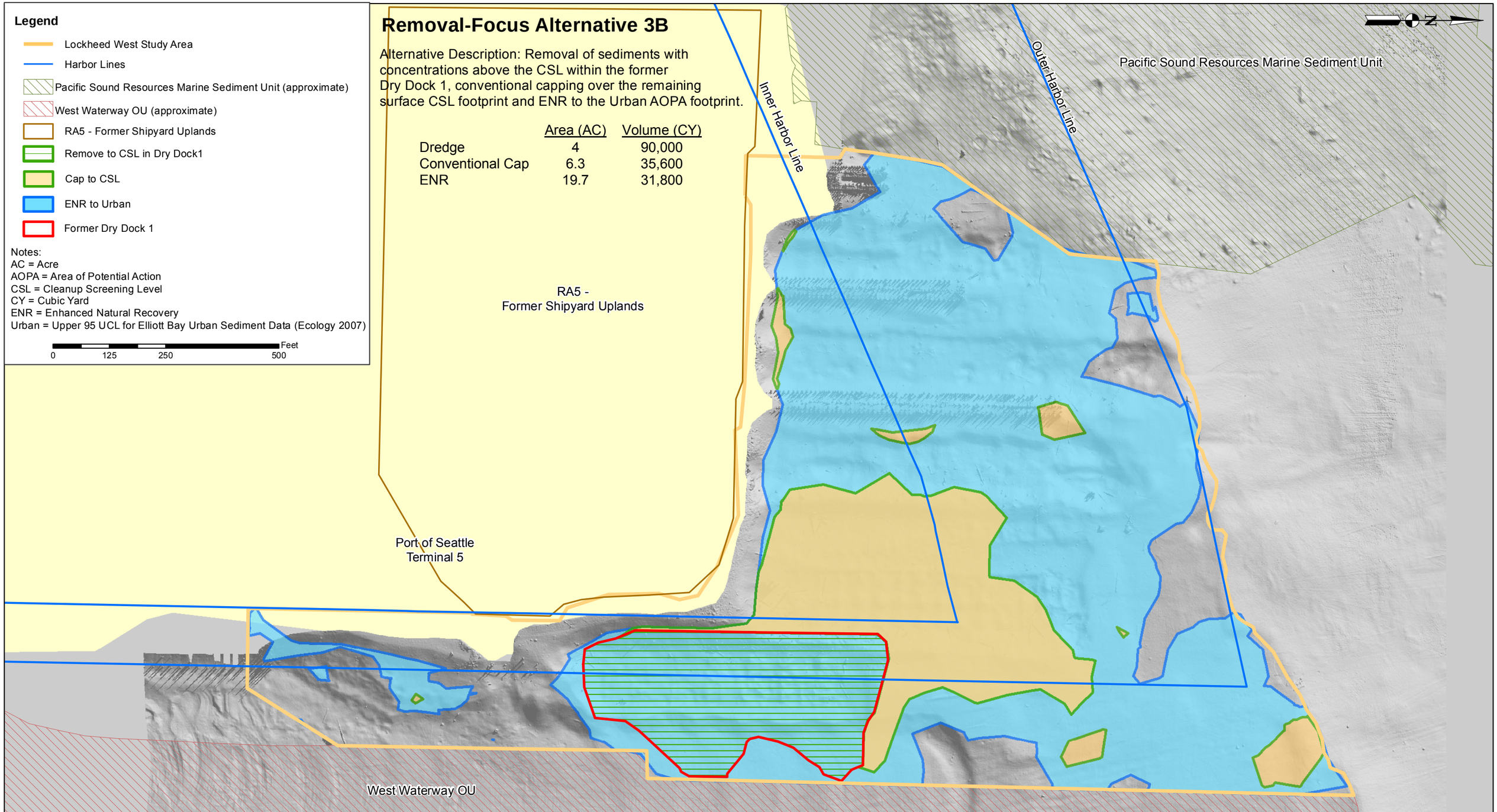

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Figure 11-13
Removal-Focus Alternative 3B

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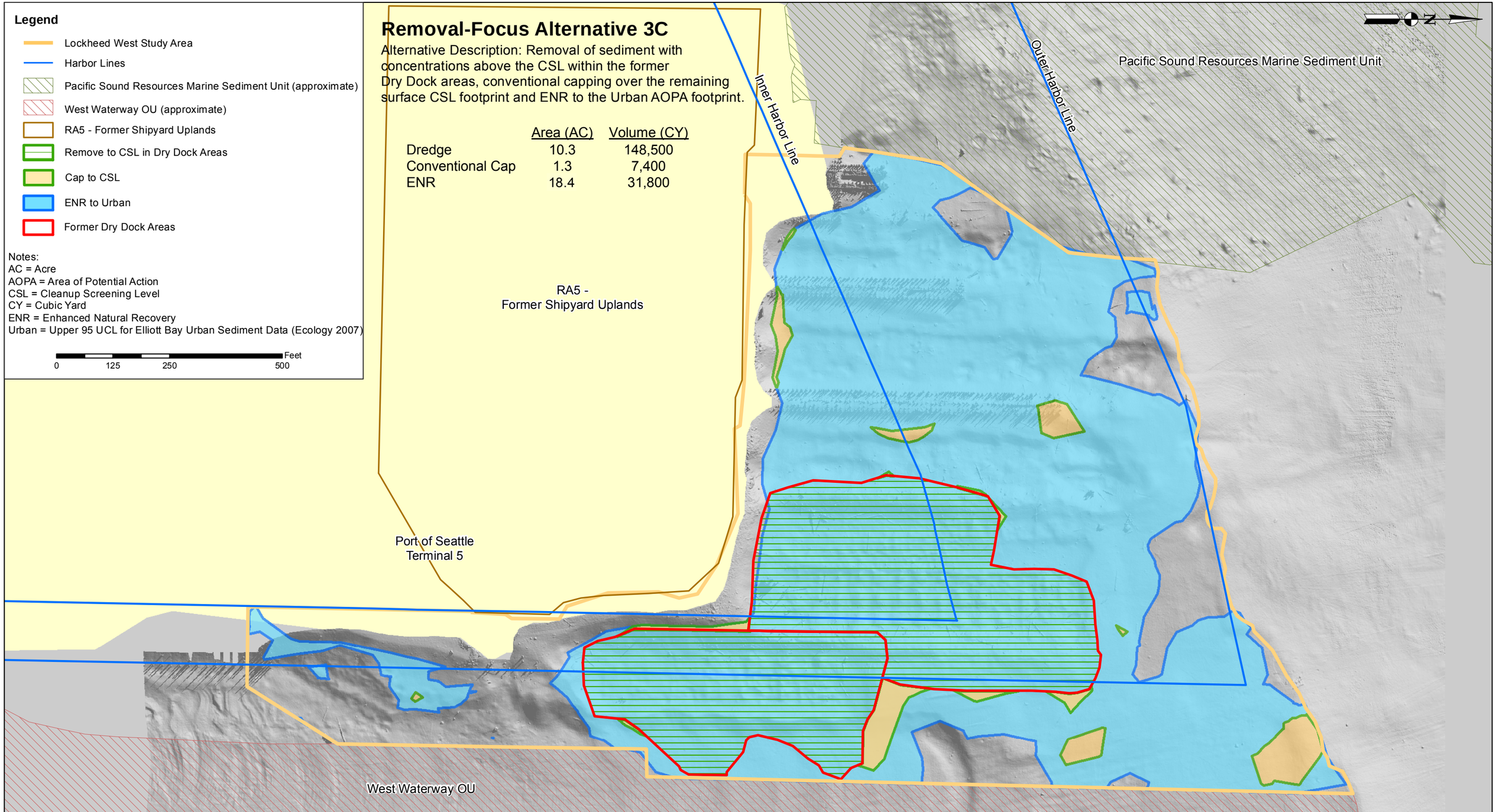

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Figure 11-14
Removal-Focus Alternative 3C

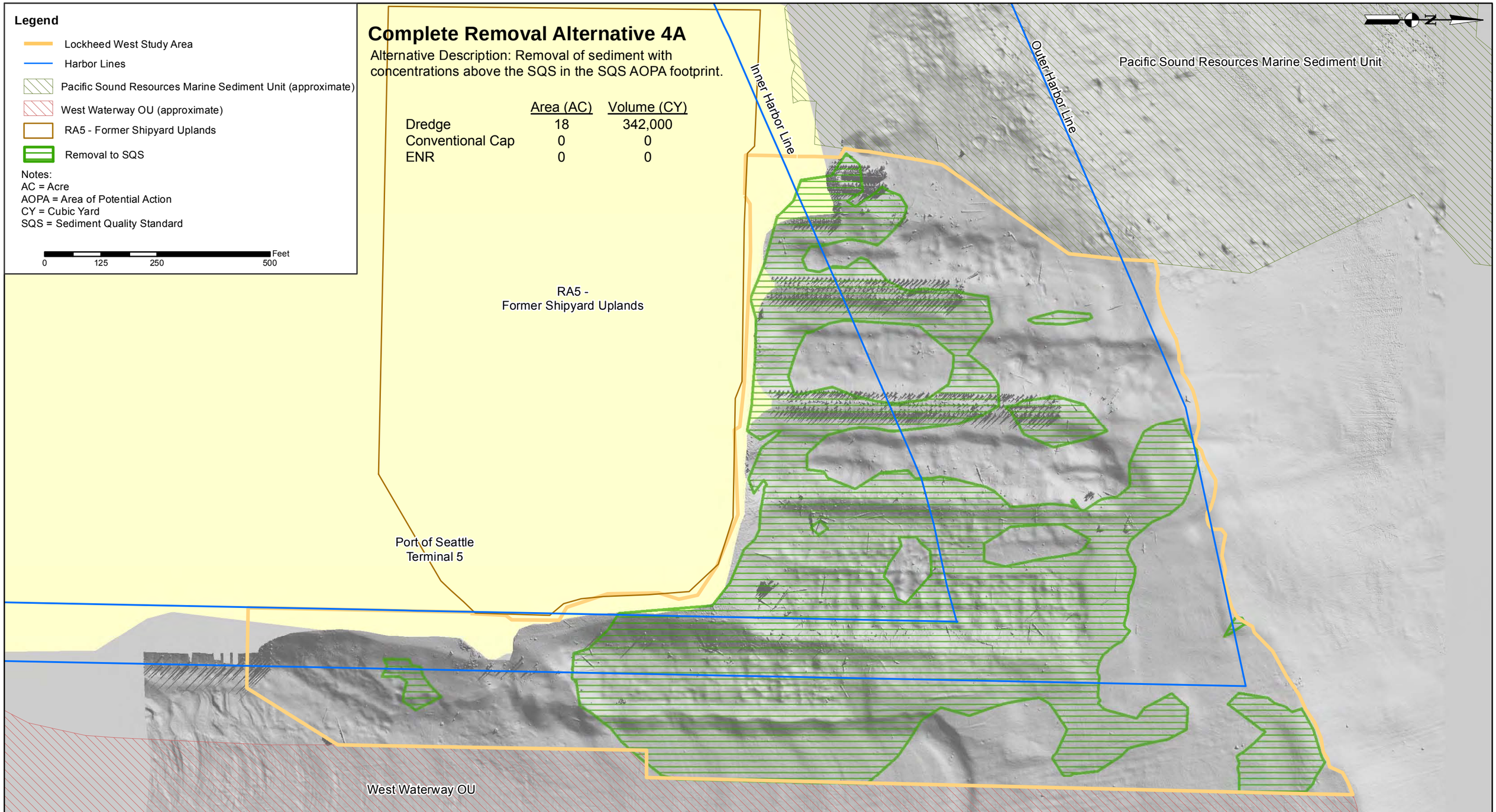

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Figure 11-15 Complete Removal Alternative 4A

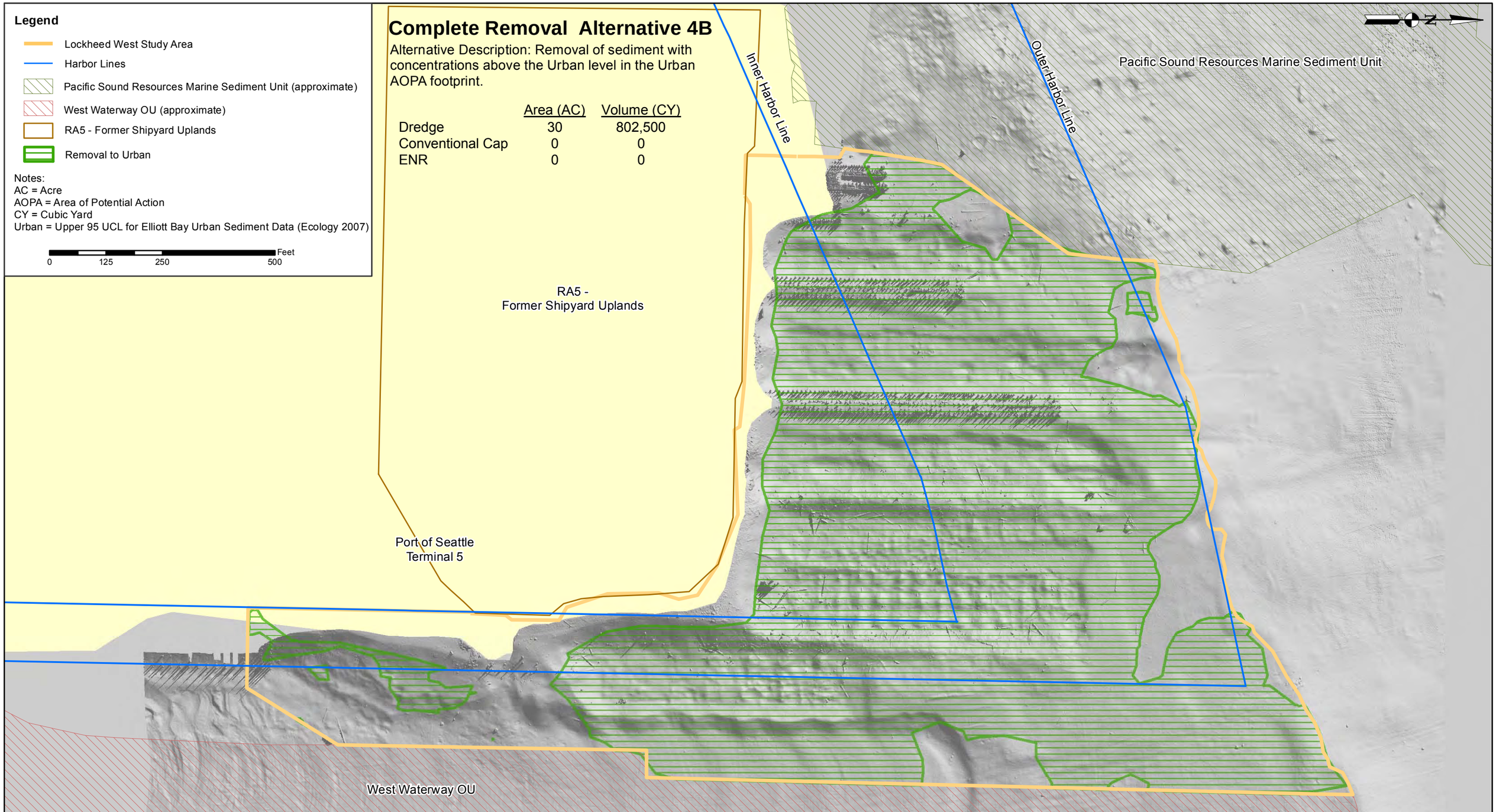

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Figure 11-16 Complete Removal Alternative 4B

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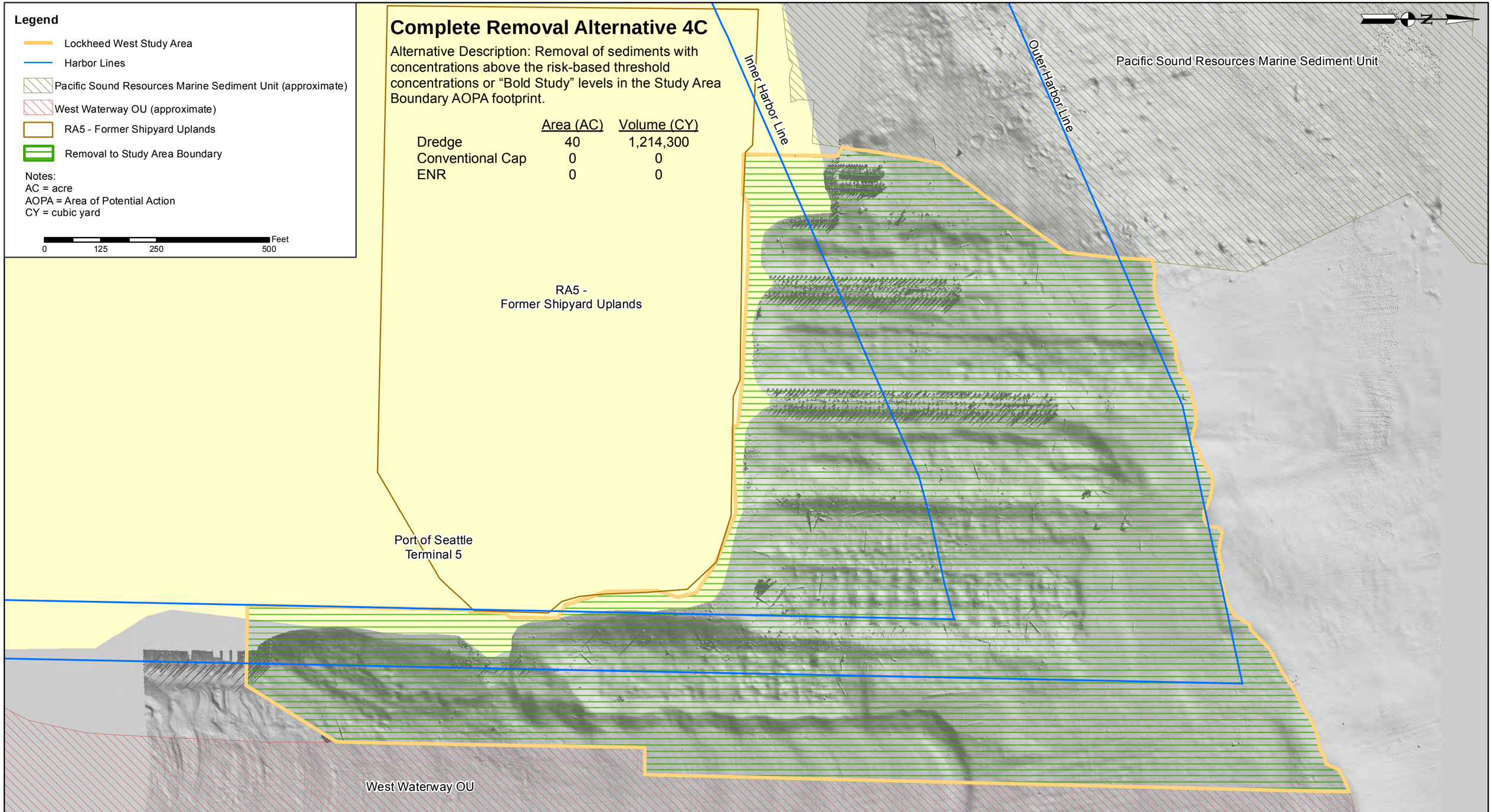

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Figure 11-17
Complete Removal Alternative 4C

SECTION 12
Detailed Evaluation of Remedial Alternatives

This section provides a detailed analysis of the alternatives developed in Section 11 for remediation of contaminated sediments in the Lockheed West Site. Late in the review process and following EPA comments on the draft RI/FS document, EPA requested consideration of several variations to the alternatives included in the detailed analysis in this section (see Appendix I). Alternatives 2A2a, 3A2, and 3C serve as base alternatives for the FS alternative variations 2A2a Plus, 3A2 Plus, and 3C Plus. The detailed analyses for these base alternatives completed in this section apply to the FS alternative variations included in Appendix I. The remedial alternatives are evaluated according to the standard criteria specified in EPA (1988) and the NCP. A comparative evaluation of the remedial alternatives under CERCLA is conducted in Section 13 to assess the relative performance of each alternative with respect to each evaluation criterion and action level, and to identify the key tradeoffs between them.

12.1 NATIONAL CONTINGENCY PLAN EVALUATION CRITERIA

EPA (1988) and the NCP (40 CFR Section 300.430[e][9][iii]) require consideration of nine evaluation criteria to address the CERCLA statutory requirements (Table 12-1). These nine evaluation criteria are categorized into three sets of criteria that serve as the basis for conducting the detailed analyses and for subsequently selecting an appropriate remedial action.

- Threshold Criteria
  - Overall protection of human health and the environment
  - Compliance with ARARs
- Primary Balancing Criteria
  - Long-term effectiveness and permanence
  - Reduction of toxicity, mobility, and volume through treatment
  - Short-term effectiveness

    - Implementability (technical and administrative feasibility)
    - Cost
- Modifying Criteria
    - State acceptance
    - Community acceptance

The NCP evaluation criteria are intended to provide a framework for assessing the risks, costs, and benefits for each remedial alternative. In this FS, the relative performance of each alternative is assessed individually and comparatively with respect to the first seven of the nine CERCLA evaluation criteria to identify the key tradeoffs among them. The last two criteria are considered modifying criteria and are typically assessed by EPA following agency and public comment on the FS in development of the EPA Proposed Plan, and then again on the Proposed Plan itself. The following subsections contain descriptions of key ideas and concepts of the specific evaluations performed in this FS to determine how well an alternative addresses a criterion.

12.1.1 Threshold Criteria

Under CERCLA, each alternative must meet the threshold criteria to be eligible for selection as the preferred alternative. This section discusses how an alternative meets these criteria, how the RAOs are achieved, and what expected statutory or other relevant requirements must be achieved during implementation of the remedial action.

12.1.1.1 Overall Protection of Human Health and the Environment

This evaluation criterion assesses whether each alternative, as a whole, achieves and maintains adequate protection of human health and the environment. The NCP (40 CFR 300.430) states that "[a]lternatives shall be assessed to determine whether they can adequately protect human health and the environment, in both the short- and long-term, from unacceptable risks posed by hazardous substances, pollutants, or contaminants present at the site by eliminating, reducing, or controlling exposures to levels established during development of remediation goals consistent with § 300.430(e)(2)(i). Overall protection of human health and the environment draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs."

Evaluation of the overall protectiveness of an alternative during the FS focuses on whether a specific alternative achieves adequate protection and should describe how site risks posed through each pathway being addressed by the FS are eliminated, reduced, or controlled through treatment, engineering, or institutional controls. This evaluation also allows for consideration of whether an alternative poses any unacceptable short-term impacts (EPA, 1988).

12.1.1.2 Compliance with Applicable or Relevant and Appropriate Requirements

This evaluation criterion considers whether the remedial alternative complies with the chemical-specific, location-specific, and action-specific ARARs. The NCP (40 CFR 300.430) states that "[t]he alternatives shall be assessed to determine whether they attain ARARs under federal environmental laws and state environmental or facility siting laws or provide grounds for invoking one of the waivers under paragraph (f)(1)(ii)(C) of this section." Section 9 of this report introduces the federal and state ARARs (refer to Tables 9-1 and 9-2). The screening conducted in this section is for those ARARs that relate to actions taken to implement the remedial alternatives. Approval and performance of the remedial alternatives will require that the actions taken comply with the ARARs to the extent practicable. Of the ARARs listed in Tables 9-1 and 9-2, three were used in determining compliance of the remedial alternatives, as follows:

- Sediment Management Standards (WAC 173-204)
- Surface Water Quality Standards (RCW 90-48; WAC 173-201A)
- State Model Toxics Control Act (WAC 173-340-700[5][d])

The other ARARs listed in Tables 9-1 and 9-2 are not discussed explicitly as part of the remedial alternative evaluation. The remedial alternatives are assumed to comply with these ARARs under the rationale that the required engineering design and agency review process will ensure that the selected remedy complies with those ARARs. The decision on compliance will be made based on details provided in the remedial design and remedial action work plan and associated sections (e.g., environmental protection plan, construction quality control plan, waste management, transportation and disposal plan, stormwater pollution and spill prevention plan, best management practices) to be prepared during design. It is therefore anticipated that all of the alternatives can be designed and implemented in compliance with ARARs pertaining to management and disposal of generated materials (e.g., contaminated sediment, wastewater, and

solid waste). These other ARARs are all largely procedural and influence how materials are handled and disposed of. They may affect implementation, but they do not have a significant effect on whether a remedial alternative is fundamentally viable.

Sediment Management Standards

The Sediment Management Standards are an ARAR under CERCLA. Cleanup standards under the SMS are established on a location-specific basis within an allowable range of concentrations. The upper end of this range is the minimum cleanup level established at a level not to be exceeded 10 years after completion of the active cleanup actions. The minimum cleanup level is the same numerical value as the CSL, which defines the upper end of minor adverse effects for benthic organisms. The lower end of the range is the cleanup objective and is equivalent to the SQS. Site-specific cleanup standards are to be as close as practicable to the cleanup objective. The SMS defines the sediment cleanup objective as the elimination of adverse effects on biological resources and significant health threats to humans from sediment contamination (WAC 173-204-570). Factors considered for identification of site-specific sediment cleanup standards include environmental effects, technical feasibility, and cost.

For the Lockheed West Site FS evaluation, the remaining sediment COC concentrations resulting from a remedial alternative are compared with the SMS (and therefore achievement of RAO 3) on a point basis.

The SMS have flexibility in defining cleanup standards and, further, the SMS allow for consideration of environmental effects, technical feasibility, and cost (WAC 173-204-200[19]). In addition, it is recognized in the FS that, given the uncertainty in predictions of residual contaminant concentrations, achievement of 100 percent compliance with the SQS may be an overly stringent expectation. In this context, small numbers of SQS exceedances may represent no more than isolated minor adverse effects on the benthic community, and those may not merit further action based on a number of factors such as bioavailability and sediment toxicity test results. Each of the remedial alternatives is designed to, at a minimum, address the current risk-driver SQS exceedances.

Surface Water Quality Standards

Compliance with surface water quality ARARs is both a short-term and long-term requirement. Dredging is the remedial technology with the greatest potential for causing short-term exceedances of water quality parameters. Placement of granular material during backfilling, capping, and ENR can also cause water quality impacts depending on material gradation, composition, application method, and rate. Chemical-specific water quality impacts are much more likely during dredging than during placement of clean granular material. However, contaminated sediment dredging projects in and near the Lockheed West Site have historically been issued water quality certifications with stipulated measures to minimize construction-related impacts (AECOM, 2010).

Active remedial measures for the water column are not technically feasible and are therefore not included as part of the remedial alternatives. While water quality improvements are anticipated from sediment remediation, it may not be possible for any alternative to meet certain federal or state ambient water quality criteria or standards. Further, potential sources of recontamination exist for the Lockheed West Site. The conclusion reached in the source control reports (Tetra Tech, 2009a,b) was that a relatively high potential for recontamination above risk-based threshold concentrations exists for selected risk-driver COCs. For this reason, more definitive statements on whether, and to what extent, certain water quality criteria will be met or potentially waived (based on technical impracticability) cannot be made at this time.

Model Toxics Control Act

The state MTCA regulations governing the selection of cleanup standards are ARARs under CERCLA. The state regulations provide that sediment cleanup levels cannot be set at concentrations lower than natural background when RBTCs (based on 1×10^{-6} excess cancer risk threshold) are below natural background (WAC 173-340-705[6]). For the Lockheed West Site, this applies to total PCBs, arsenic, lead, and cPAHs for the human seafood consumption scenario and arsenic for all direct contact scenarios. The associated PRGs for these contaminants and scenarios were defined in Section 9.4 based on estimates of natural background using the 2007 “Bold Study” data set (EPA, 2009a). All of the containment- and removal-focus alternatives leave contaminated sediment on-site above the estimated natural background cleanup levels for total PCBs and cPAHs. They comply with the MTCA ARARs by a combination of reducing

concentrations and using institutional controls designed to reduce human consumption of resident fish and shellfish (WAC 173-340-360 and -370).

12.1.2 Primary Balancing Criteria

Primary balancing criteria are used to weigh effectiveness and cost tradeoffs among alternatives. These criteria represent the main technical criteria upon which alternative evaluation is based. Table 12-1 presents the five primary balancing criteria under CERCLA and a summary of the evaluation factors used to assess each one. These criteria and their evaluation are described in detail in the following subsections.

12.1.2.1 Long-term Effectiveness and Permanence

Long-term effectiveness and permanence provide a means of evaluating the final risk at the site once the active remedial work has been completed. The NCP (40 CFR 300.430) states that "[a]lternatives shall be assessed for the long-term effectiveness and permanence they afford, along with the degree of certainty that the alternative will prove successful." Per 40 CFR 300.430(e)(iii)(C), the factors that shall be considered, as appropriate, include the following:

1. Magnitude of residual risk remaining at the conclusion of the remedial activities. The characteristics of the residuals should be considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate.
2. Adequacy and reliability of controls such as containment systems and institutional controls are necessary to manage residuals. This factor addresses in particular the uncertainties associated with land disposal for providing long-term protection from residuals; the assessment of the potential need to replace technical components of the alternative, such as a cap, a slurry wall, or a treatment system; and the potential exposure pathways and risks posed should the remedial action need replacement.

Following the NCP guidance, general analysis factors considered during evaluation of each alternative for long-term effectiveness and permanence are the magnitude of surface and subsurface residual risks and the adequacy and reliability of controls. The evaluation of magnitude of residual risks is focused on the identification of residuals remaining after completion of the remedy (i.e., unremoved sediments with concentrations of COCs above the cleanup goals) and the magnitude of the remaining risks.

Magnitude of Surface Sediment Residual Risks

The magnitude of surface contamination remaining under each remedial alternative was evaluated by estimating a sitewide average residual surface sediment concentration determined for each sampling point from the RI/FS sample data (see Section 4). The residual risk for each alternative was not calculated because the risk calculation using the LDW food web model is driven by the assumed surface water PCB concentration, which results in a risk level of 2×10^{-4}. For the range of sitewide average surface PCB concentrations calculated for the alternatives, the residual risk for PCBs ranges from 2×10^{-4} to 2.8×10^{-4}.

For the alternatives with a capping and ENR component, the following procedures were applied to the location point data to calculate the sitewide residual concentrations. If a point is inside a capped area, the surface concentration for the risk-driver COC is replaced with the natural background value or an assumed concentration of capping import material for the analytes. If a location is in an ENR area, the surface concentration at that point location is reduced 50 percent to reflect the complete mixing of the thin layer (e.g., 6 inches) of clean material with the underlying surface sediments. If a location is in a non-cap and non-ENR area, the sediment risk-driver concentrations are left at the reported sample results.

For the alternatives with a dredging component, the concentration from the underlying sediment interval to which the removal reaches at each point location is used for the resulting initial residual surface sediment concentration. If the resulting initial residual surface concentration was above two times the SQS for any of the risk-driver compounds (i.e., the level below which ENR is assumed in the FS to be effective based on the description of applying ENR in Section 10.6), a conventional cap was anticipated to be placed and the initial residual surface concentration was replaced with the natural background concentrations or an assumed concentration of capping import material. If no cap was anticipated, a 6-inch residuals backfill layer is expected to be placed resulting in a 50 percent reduction in the initial residual surface sediment concentration. If the lowest sample point interval has a concentration above the removal basis, the risk-driver contaminants with concentrations above the SQS were replaced with a concentration equal to the SQS level for the resulting surface sediment concentration.

The average and 95 UCL of the point residual surface concentrations were estimated for all locations across the Site. This sitewide average residual surface concentration was used to determine if remedial activities applied in the alternative resulted in achieving the PRGs for the RAOs. The performance of alternatives to achieve RAO 1 PRGs was assessed by estimating an incremental risk reduction (i.e., progress toward reaching RAO 1 PRGs from mean baseline conditions; the No Action concentrations) for each alternative. First, sitewide average residual surface sediment concentrations for each risk-driver COC were estimated for each remedial alternative. Then, the calculated sitewide average concentrations were compared with the residual sitewide risk-driver COCs under the No Action alternative, which represent the mean baseline conditions. Incremental risk reduction (i.e., progress toward reaching RAO 1 PRGs from mean baseline) to achieve RAO 1 PRGs was estimated through this comparison by computing the following ratio:

$$Progress\ to\ RAO1 = \frac{(Mean\ Baseline\ Concentration - Sitewide\ Average\ Residuals\ Concentration\ )}{(Mean\ Baseline\ Concentration\ - PRG\ Concentration)} x\ 100$$

The results of this analysis are summarized in Tables 12-2 and 12-3 and discussed in the detailed evaluation of each alternative.

Magnitude of Subsurface Residual Risks

The sediment core data statistics gathered during the RI provide a reasonable approximation of COCs remaining in the subsurface after remediation is completed but are limited for approximating the potential for re-exposure of COCs. Re-exposure potential was qualitatively gauged using the number of sediment cores in the FS data set with concentrations above SMS criteria (i.e., SQS and CSL) and that are located within areas that are dredged, capped, or undergo ENR. Summary statistics for FS data set cores remaining in actively remediated areas were grouped into two depth intervals (i.e., 0 to 3 feet and deeper than 3 feet) and compiled in Table 12-4. Some of these are co-located with CSL and SQS exceedances, and deeper cores may be covered by cleaner sediments. This data set was qualitatively evaluated to assess the potential for recontamination from remaining residuals for each alternative. Using this core data, residual risk-driver contaminant concentrations for containment- and removal-focus alternatives after remedy were also compiled. This data set shows the sediment concentrations for the risk-driver COCs that remain at the RI sampling locations and the approximate depth in the underlying

sediment below the post-remedy construction mudline surface prior to cap, dredge backfill, or ENR layer placement. Potential mechanisms for re-exposing subsurface sediment include high-flow scour, propeller wash, construction activities, and seismic events. Earthquakes could cause recontamination either from ground disturbances and related impacts to sediment caps, or from tsunami scour. Seismic stability and liquefaction potential of subsurface sediment were evaluated and are presented in Appendix H. The findings indicated that excessive deformation and ground movement intersecting contaminated sediments is unlikely in the project site footprint for a nominal 100-year event, and likely for 500-year and 2,500-year events. When ground movement intersecting contaminated soils is predicted, lateral displacements and sediment movements were predicted to be in the range of 1 to 20 feet. The seismic evaluation for the Site (see Appendix H) does not suggest occurrence of a large-scale flow slide that may affect the stability of contaminated sediments. However, a potential risk for a flow slide exists for the region based on the findings of previous seismic stability analyses of the Duwamish River delta near Elliott Bay and Harbor Island (Kayen and Barnhardt, 2007). Liquefaction-induced deformation analysis results indicate that there is a risk of potential upwelling, exposure, and spreading of contaminated sediments beneath the capped and ENR areas. In general, the majority of subsurface sediment disturbances are likely to be localized and have a low potential for increasing sitewide average concentrations to compromise RAOs 1, 2, and 4. The potential for recontamination from these mechanisms generally decreases with the depth of contamination and as the surface area containing subsurface contamination decreases.

Physical re-exposure potential differs between cap and ENR areas. Caps are engineered systems to ensure isolation and permanence in which the cap thickness and material are selected based on well-understood design principles, experience gained through widespread use at other sites, and site-specific predetermined design criteria. The physical re-exposure potential from ENR areas presents a slightly higher risk than capped areas because ENR is not an isolation cap and is only applied to the areas where conventional isolation capping is not required to achieve RAOs. ENR areas are designed such that over the long term, the surface (6- to 9-inch clean layer) and near surface sediments will reach an equilibrium through bioturbation and other mixing activities (i.e., wind and wave action, scour), and a surface layer with contaminant concentrations within acceptable levels will be maintained in the long term at steady-state conditions. Although ENR areas are designed to be mixed with underlying near surface sediments by natural and future site

use mixing activities, the physical re-exposure potential from ENR is considered slightly higher than from the capped areas. The risk from the physical re-exposure of surfaces undergoing ENR is assumed to decrease as the remaining number of cores with SMS exceedances decrease.

Adequacy and Reliability of Controls

The assessment of the adequacy and reliability of controls focuses on monitoring, maintenance, and institutional controls. The No Action alternative is assumed to have none of these controls. The analysis is focused on the following considerations:

- Likelihood that the technologies will meet required process efficiencies or performance specifications;
- Type and degree of long-term management required;
- Long-term monitoring requirements;
- O&M functions that must be performed;
- Difficulties and uncertainties associated with long-term O&M functions;
- Potential need for technical components replacement;
- Magnitude of threats or risks, should technical components need replacement;
- Confidence that controls can adequately handle potential problems; and
- Uncertainties associated with land disposal of residuals and untreated wastes.

One important consideration for long-term effectiveness and permanence under all the Lockheed West Site remedial alternatives is potential recontamination. The evaluation of multiple lines of evidence indicates that there is uncertainty about the magnitude of the impact to the remedy from potential off-site sources for sediment recontamination at the Site. As discussed in Section 5, the source control evaluation shows that the potential source contaminant concentrations are likely above potential sediment cleanup goals for the Site that are based on natural background, while the likelihood of sediment recontamination above the SQS standards used as cleanup levels for nearby sediment sites is relatively low (Tetra Tech, 2009b). The long-term concentrations for COCs at the Site are expected to be in the range between the natural background levels and the concentrations found in the Elliott Bay region based on concentrations from monitoring completed at adjacent Superfund sites that have been remediated in the past 5 to 7 years (see Table 5-1). In this FS, potential sediment recontamination via in-water sources is a common

uncertainty for each remedial alternative during evaluation of its long-term effectiveness and permanence.

The intensity of monitoring and maintenance of the proposed alternatives are assumed to increase in proportion to the area undergoing remediation by capping and ENR. Areas that are dredged or capped yield immediate and more permanent concentration and risk reduction. Unremediated no action areas outside of the active remediation areas within the study area boundary also require monitoring. For each alternative, sitewide monitoring and bathymetric surveys will be used to determine the condition of the remedy. Seismic analysis findings indicated that when ground movement intersecting contaminated sediments is predicted during nominal 500-year and 2,500-year events, lateral displacements and sediment movements would be such that corrective measures, such as cap repair and/or replacement, would be feasible. Based on the liquefaction-induced deformation analysis, there exists a risk of potential upwelling, exposure, and spreading of contaminated sediments beneath the capped areas due to liquefaction; however, the hazard is expected to be localized and retained within the dry dock hot spot area. Monitoring would be conducted after a seismic event exceeding the design criteria. Repairs, if needed, would be consistent with the original remedial design intent, such as maintaining a 3-foot sand layer where a conventional cap was applied. Refer to Appendix H for detailed seismic evaluation of remedial alternatives.

Institutional controls are a required element of Alternatives 2 through 4. An institutional controls plan for the Lockheed West Site will include seafood consumption advisories, public outreach, and education programs. The plan will also include the use of restrictive covenants as the primary proprietary control used in environmental remediation actions by limiting the ability of the owners of the property subject to the covenant from conducting any activity that could result in the release or exposure to the environment of residual contamination. Regardless of the cleanup remedy, EPA will closely work with property owners as new developments occur to make sure that development can happen while implementing short-term controls to minimize potential residual risks. Institutional controls would manage construction-related recontamination from future projects unrelated to the remedy selected for this project. Within the institutional controls, a monitoring element associated with the waterway use and permit application process serves to identify and alert EPA of projects that are being proposed in areas with residual

contamination. The regulatory agencies can then track and influence the design by specifying use of construction-related best management practices and monitoring.

Specific institutional controls potentially applicable to the cap areas include the following:

- Governmental controls (i.e., monitoring and notification of waterway users):
    - Restrictive anchorage within the areas that are capped;
    - Restrictive grounding of small vessels on the shoreline;
    - Restrictions of vessel draft, horsepower, speed, and time in area; and
    - Restrictions on piling placement or removal through cap, or special maintenance requirements;
- Proprietary controls (i.e., easements and restrictive covenants related to cap);
- Enforcement and permit tools (i.e., administrative orders, consent decrees); and
- Informational devices (i.e., seafood consumption advisories, education and public outreach, and site registry).

Because the Site is a tribal U&A area, a remedy should be designed to reduce conflicts or restrictions on tribal treaty fishing rights or other treaty protected rights such as anchorage of tribal fishing vessels or access to aquatic resources. Therefore, out of the institutional controls listed above, restrictions on anchorage and grounding of tribal vessels or access to resources will be minimized or eliminated during the remedial design (e.g., applying a thick cap). For the FS-level evaluation, no institutional controls from the list above were eliminated and all are considered applicable to the alternatives with a cap remedy.

Specific institutional controls applicable to the ENR and dredge areas include informational devices such as education and public outreach and seafood consumption advisories.

Those alternatives with a removal component may also require, in addition to long-term institutional controls, short-term fish consumption advisories due to short-term impacts during remedial construction when the highest sediment contaminant concentrations are being actively dredged.

For FS evaluation purposes, the adequacy and reliability of the controls (monitoring, maintenance, and institutional controls) are considered proportional to the area remediated by capping and ENR.

12.1.2.2 Reductions in Toxicity, Mobility, and Volume through Treatment

The next criterion assesses the degree to which site media are treated to reduce the toxicity, mobility, or volume of site contaminants permanently and significantly. The NCP (40 CFR Section 300.430[e][9][iii][D]) states that "[t]he degree to which alternatives employ recycling or treatment that reduces toxicity, mobility, or volume shall be assessed, including how treatment is used to address the principal threats posed by the site." This assessment is accomplished by analyzing the destruction of toxic contaminants, the reduction of the total mass of toxic contaminants, the irreversible reduction in contaminant mobility, or the reduction in total volume of contaminated material that is accomplished by one or more treatment components of the remedial alternative.

The NCP (40 CFR Section 300.430[a][1][iii]) states that EPA "generally shall consider the following expectations in developing appropriate remedial alternatives:

- …use treatment to address principal threats posed by a site, wherever practicable. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials.
- …use engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable."

The EPA guidance (EPA, 1991b) defines principal threat waste as a source material that is highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur, such as drummed waste or pools of non-aqueous phase liquids. Per 40 CFR 300.430(a)(iii), EPA expects that treatment will be used for principal threat waste whereas engineering and/or institutional controls will be used for low-level threat waste. For the majority of sediment removed from Superfund sites in the U.S., treatment is not conducted prior to disposal, generally because sediment sites often have widespread low-level contamination (EPA, 2005b). Pretreatment, such as particle size separation

for hazardous/non-hazardous waste disposal, if used at all, is the most common treatment technique used at sediment sites. No non-aqueous phase liquids have been found in the Lockheed West Site sediments. Concentrations of COCs at the Site, like most sediment sites, are classified as low-level threat wastes, not principal threat waste. The maximum concentrations detected for the human health risk-driver contaminants in surface and subsurface sediment are: 374 mg/kg for arsenic, 2,620 mg/kg for copper, 2,200 mg/kg for lead, 17.1 mg/kg for mercury, 9.62 mg/kg dw for total PCBs, 17.2 mg/kg dw for cPAHs, and 9.1 mg/kg dw for TBT, none of which are classified as principal threat wastes. As discussed in Section 10.9, no treatment technologies are retained for further consideration in the Lockheed West Site FS and therefore no remedial alternative has a treatment component.

The main elements of the remedial alternatives are removal and disposal, capping, and ENR, which are not categorized as treatment technologies under CERCLA but are consistent with the NCP suggested use of engineering controls to address low-level threat wastes. These technologies reduce mobility and toxicity even though they do not address the NCP criterion for treatment of principal threat wastes. For example, once contaminated sediment is dredged and disposed of at a landfill, receptors such as humans, fish, and wildlife cannot come into contact with the material. Capping physically and chemically contains the contaminant, thereby reducing mobility and exposure potential. Similarly, ENR reduces surface sediment concentrations through burial, which in turn reduces mobility and toxicity.

12.1.2.3 Short-Term Effectiveness

Short-term effectiveness is evaluated based on the impacts on human health and the environment during implementation of the active remediation components of each alternative. Per NCP 40 CFR Section 300.430(e)(9)(iii)(F), “[t]he short-term impacts of alternatives shall be assessed considering the following:

- Short-term risks that might be posed to the community during implementation of an alternative;
- Potential impacts on workers during remedial action and the effectiveness and reliability of protective measures;

- Potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation; and
- Time until protection is achieved."

Short-term environmental impacts of the active remedial actions are qualitatively evaluated consistent with EPA's Green Remediation policy to enhance the environmental benefits of federal cleanup programs by promoting technologies and practices that are sustainable (EPA, 2008b, 2009f, 2010b). This evaluation and a series short-term impact metrics are presented in this FS to enhance the short-term effectiveness evaluation of each alternative. Green remediation evaluation does not serve as a criterion for remedy selection. Currently, EPA plans to issue OSWER policy on how green remediation strategies can factor into the NCP's nine evaluation criteria for remedy selection and the Superfund evaluation criteria (EPA, 2010b).

Short-term environmental impacts are evaluated, in part, based on habitat disturbance, consumption of natural resource materials (e.g., for capping), landfill capacity utilization, transportation mileage, particulate matter, and gas emissions. The degree of habitat disturbance is measured as the amount of active remediation in intertidal and shallow subtidal areas above -10 feet MLLW (e.g., shoreline/intertidal remediation). Transportation mileage, carbon dioxide (CO_2) emissions and particulate matter with a diameter of 10 micrometers or less (PM_{10}) emissions are used to evaluate potential short-term impacts to the community and workers. Most recently, these short-term impacts have been evaluated for the LDW FS (AECOM, 2010). Similar methodology and assumptions were followed to estimate short-term metrics and are presented in Appendix G. As part of short-term impacts, general disruptions and inconveniences to the public and commercial community, such as noise and lights from night-time operations, traffic, and temporary waterway restrictions, can be expected to increase with the increased duration of construction.

Fish and shellfish tissue concentrations are also assumed to increase during the time when the highest sediment contaminant concentrations are being actively dredged. At Lower Fox River OU1, fish-tissue PCB concentrations increased above background levels during dredging but declined rapidly to substantively lower than expected levels post-remedy, similar to what has been observed at other large dredging and remedial projects (WDNR, 2011). The Lower Fox River OU1 post-remediation executive summary noted that fish tissue PCB concentrations

responded to the ROD remedy in a way that is consistent with other large dredging sites (e.g., at Bryant Mill Pond, part of the Allied Paper/Kalamazoo River/Portage Creek Superfund Site) where the PCB concentrations increased in fish captured during the years in which dredging occurred, but subsequently declined quickly thereafter illustrating the benefit of the remedy. Similarly, at the Hudson River PCBs Superfund site, PCB concentrations increased during dredging, but also declined in the first year of monitoring post-dredging (WDNR, 2011). Consistent with the expected short-term elevated fish and shellfish tissue concentrations, the dredge areas of FS alternatives may require short-term fish consumption advisories to protect consumers of resident seafood during construction. The EPA's Green Remediation strategy recognizes that opportunities to decrease the environmental footprint of cleanup activities and maximize the environmental outcome of a cleanup exist throughout a project life, extending from site investigation through development of cleanup alternatives and remedy design, construction, operation, and monitoring (EPA, 2008b, 2009f, 2010a). Green remediation comprises a range of best practices that may be applied throughout the Superfund cleanup process. The best management practices of green remediation provide potential means to improve waste management; conserve or preserve energy, fuel, water, and other natural resources; reduce greenhouse gas emissions; promote sustainable long-term stewardship; and reduce adverse impacts on local communities during and after remediation activities. Consistent with EPA's Green Remediation strategy, Lockheed Martin would explore and implement sustainability measures to reduce the environmental footprint of cleanup activities developed in this FS to the maximum extent possible during remedial design and implementation. These sustainability measures were not discussed under detailed evaluation of short-term environmental impacts of each alternative; however, potential measures and best management practices that could be applied during cleanup activities are briefly discussed in Appendix G.

12.1.2.4 Implementability

This evaluation criterion is used to consider the technical and administrative feasibility of implementing the remedial alternatives. The following factors are considered during the implementability evaluation:

- Technical Feasibility – Relative ease of implementing or completing the remedial alternative based on site-specific constraints (e.g., the remedial alternative's

constructability and operational reliability, as well as the ability to monitor the effectiveness of the remedial alternative);

- Administrative Feasibility – Coordination with other agencies (e.g., the steps required to coordinate with regulatory agencies, to establish long-term or future coordination among agencies, and the ease of obtaining permits for off-site activities, if required); and
- Availability of Services and Materials – Availability of adequate treatment, storage facility/capacity, and handling/disposal facilities/services; availability of adequate equipment and specialists.

12.1.2.5 Cost

This criterion refers to the total cost to implement each remedial alternative. The total cost represents the sum of the direct capital costs (materials, equipment, and labor), indirect capital costs (engineering, management, and contingency allowances), and annual and periodic costs (O&M costs, monitoring, and ongoing administration). These total costs, which are developed to allow the comparison of the remedial alternatives, are estimated with expected accuracies of -30 to +50 percent, in accordance with EPA (1988) guidance.

The cost estimates developed in this FS are expressed in current (2012) dollars and the costs of remedial alternatives are compared using the estimated present value of the alternative. The net present value allows costs for remedial alternatives to be compared by discounting all costs to the year that the alternative is implemented. In the *Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA, 2000b), EPA suggests that the period of analysis for the present value analysis should be equivalent to the project duration of 30 years, to provide a complete life cycle cost estimate of the remedial alternative. Most of the remedial alternatives developed for the Lockheed West Site require long-term activities, including institutional controls and maintenance of constructed caps, and are calculated using discount factors consistent with CERCLA cost estimation guidance. The discount factor is assumed to be 3 percent for institutional controls and long-term operation and maintenance costs. The alternatives with cap and ENR components have costs associated with the institutional controls and the long-term O&M activities longer than a 30-year period. For the cap alternatives, because a cap stays forever, associated institutional controls and long-term O&M costs remain indefinitely. The FS cost estimates of all alternatives were calculated for a 30-year duration for a consistent comparison between the alternatives. The longer life cycle of remedies associated with cap and

ENR components was considered in other NCP criteria comparative analyses. Indirect costs including bid and scope contingency, project management, remedial design, and construction management/field activity oversight were added to capital costs as percentages of the total cost. Percentages were determined based on the uncertainty, total cost, and/or complexity of the project. The FS cost estimates of each alternative and the cost estimate assumptions are provided in Appendix F.

12.1.3 Modifying Criteria

Modifying criteria are state acceptance and community acceptance, which may be used to modify aspects of the preferred alternative when preparing the ROD. Modifying criteria will be evaluated after the FS is released for regulatory and public review, following analysis of public comment on the Proposed Plan. During development of this FS, community and stakeholder comments and concerns have been and will continue to be considered by EPA. EPA will evaluate state, tribal, and community acceptance in the final decision document following the public comment period on the FS and on EPA's Proposed Plan.

12.2 DETAILED ANALYSIS OF ALTERNATIVE 1: NO ACTION

The No Action alternative reflects the baseline Site conditions. Alternative 1 does not include any active remediation, monitoring, or institutional controls and contaminated sediments would be left in place.

12.2.1 Threshold Criteria

The No Action alternative is not protective of human health and the environment, the RAOs would not be achieved, and it does not meet the threshold criterion of achieving RAOs, one of which is to reduce ecological and human health risks associated with sediment contamination within the site to acceptable levels.

Recent risk assessments showed unacceptable risks to human health and the environment (Tetra Tech and Pascoe, 2009a,b). All current risks would remain unabated under the No Action alternative. Although degradation and other fate-and-transport processes would likely continue to reduce the COCs, concentrations associated with recently deposited sediments from ongoing sources would continue contributing to the contamination at the site (Tetra Tech, 2010b).

Changes in overall risk from the site would be difficult to assess because no monitoring would be performed under this alternative.

12.2.2 Primary Balancing Criteria

Because this alternative includes no remedial actions, the magnitude of residual risks remains the same, with any future changes occurring only through natural processes. Untreated contamination in sediment would continue to pose risk to human health and the environment. The No Action alternative is the least-cost alternative but provides limited adequacy and reliability in terms of long-term risk controls, source control, and reduction of exposure pathways. The alternative would be easy to implement because no action is being taken. The alternative would have no associated costs.

12.3 DETAILED ANALYSIS OF ALTERNATIVE 2: CONTAINMENT-FOCUS

The containment-focus Alternative 2 includes conventional capping or ENR where risk-driver COC concentrations are greater than RALs. This general alternative includes eight subalternatives (2A1, 2A2a, 2A2b, 2A3, 2A4a, 2A4b, 2A4c, and 2B) referred to as containment-focus alternatives; it would actively remediate between 18 and 40 acres through a combination of capping, ENR, and removal (Figure 12-1). The technology application areas, scope, performance, and cost summaries are presented in Table 12-2.

12.3.1 Overall Protection of Human Health and the Environment

The containment-focus Alternative 2 meets the RAOs of reducing ecological and human health risks by providing incremental risk reduction for RAO 1 by making progress toward PRGs and utilizing institutional controls and achieving PRGs associated with RAOs 2, 3, and 4. The containment-focus alternatives are estimated to be completed in one construction season. Estimated time to achieve RAOs is at the completion of construction. The performance of alternatives to achieve the RAO 1 PRGs was assessed by estimating an incremental risk reduction (i.e., progress towards reaching RAO 1 PRGs from mean baseline concentrations) for each alternative. First, sitewide average residual surface sediment concentrations for each risk-driver COC were estimated for each remedial alternative. Then, these concentrations were compared with the residual sitewide risk-driver COC concentrations under the No Action alternative, which represent the mean baseline conditions. Incremental risk reduction (i.e.,

progress towards reaching RAO 1 PRGs from mean baseline) to achieve RAO 1 PRGs was estimated through this comparison. This analysis, as well as the performance of each alternative to achieve PRGs associated with RAOs 2, 3, and 4, is presented in Table 12-3 and summarized in Table 12-2. Progress towards reaching RAO 1 average PRGs for each alternative is in the range of 89 percent (Alternative 2A1) to 100 percent (Alternative 2A4c) (Tables 12-2 and 12-3). At the end of construction, the remedies produce a clean surface over the areas remediated, achieving the PRGs for all RAOs in the short term. Over the long term, the surface and near surface sediments will reach an equilibrium concentration through mixing as described for ENR application at the Site. Some deposition of new sediment over the post-construction surface is expected to occur. The long-term concentrations for COCs at the Site are expected to fall between the natural background levels and the concentrations found in the Elliott Bay region. Containment can provide long-term protection of human health and the environment as long as the system remains intact. Monitoring of the cap structure will be required to ensure containment and structural integrity. A long-term monitoring O&M program to verify performance of the cap and to respond to potential cap damage is required and is considered to be reliable for all containment alternatives.

The overall protectiveness of the alternative will be further enhanced by institutional controls for areas that are capped. Proposed controls include identification of the capped areas as restricted anchoring zones to ensure that the integrity is not impacted during future potential construction.

Specific institutional controls potentially applicable to the cap areas of each containment-focus alternative include the following:

- Governmental controls (i.e., monitoring and notification of waterway users):
    - Restrictive anchorage within the areas that are capped;
    - Restrictive grounding of small vessels on the shoreline;
    - Restrictions of vessel draft, horsepower, speed, and time in area; and
    - Restrictions on piling placement or removal through cap, or special maintenance requirements;
- Proprietary controls (i.e., easements and restrictive covenants related to cap);
- Enforcement and permit tools (i.e., administrative orders, consent decrees); and

- Informational devices (i.e., seafood consumption advisories, education and public outreach, and site registry).

Specific institutional controls applicable to ENR and unremediated no action areas within the study area boundary for each containment-focus alternative include informational devices such as education and public outreach and seafood consumption advisories.

It is the intent of this project that restrictions on anchorage and grounding of tribal vessels will be minimized or eliminated during design because the Site is a tribal U&A area. The administrative implementability of some institutional controls, such as restricted anchorage and navigation zones within federal and state waterways, will be discussed with the Tribes and other responsible agencies. The scale of institutional controls regarding notification of waterway users by identifying cap areas as restricted zones will increase in proportion to the proposed cap area for each alternative.

Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations are similar but in increasing scale as the actively remediated areas and the scope of active remediation activities increase within the alternatives. Protection of workers and the community from physical injury is manageable with appropriate planning and standard construction practices. Institutional controls are required to protect consumers of resident Lockheed West Site seafood during and after construction.

The potential for re-exposure of subsurface contaminated sediment following active remediation is considered low and would be primarily from areas managed by ENR. Alternatives 2A4a, 2A4b, and 2A4c would not leave any known areas with CSL or SQS exceedances within the top 3 feet of sediments within remediated areas. All other containment-focus alternatives would leave, in the ENR areas, between two and seven known locations having sediment concentrations above the CSL or SQS for some risk-driver COCs in the top 3 feet of sediment (Table 12-4, Figure 12-2).

Containment-focus alternatives are further evaluated for their overall protectiveness of human health and the environment through long-term effectiveness and permanence and short-term effectiveness criteria evaluations provided below.

12.3.2 Compliance with ARARs

Containment-focus alternatives are expected to comply with ARARs at the completion of construction except as follows:

- Alternative 2A4c is predicted to achieve RAO 1 PRGs for human seafood consumption at completion of construction. All the other containment-focus alternatives are unlikely to achieve the RAO 1 PRGs directly. These PRGs are based on natural background and it is generally not practicable to achieve natural background concentrations for these contaminants at the Lockheed West Site. Compliance with the MTCA ARARs is achieved by reducing concentrations and by using institutional controls designed to reduce human exposure to resident fish and shellfish.

- Surface water quality at the Lockheed West Site is expected to improve as a result of sediment remediation to the extent that contamination from the Site sediments was contributing to the contaminant concentrations in the surface water. However, compliance with some water quality standards may not be feasible, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs, and due to uncontrolled in-water sources.

Waivers of ARARs based on technical impracticability may be required for one or more of the above conditions depending on what cleanup levels are established in the remedy decision documents and on long-term monitoring results.

12.3.3 Long-Term Effectiveness and Permanence

General analysis factors considered during detailed evaluation of alternatives for long-term effectiveness and permanence are the magnitude of residual risks and the adequacy and reliability of controls.

12.3.3.1 Magnitude of Residual Risks

The remedial alternatives were evaluated for three types of residual risk: surface and subsurface residual contamination and contaminant mass removal.

Magnitude of Surface Sediment Residual Risks

The magnitude of surface contamination remaining under the containment-focus alternatives was evaluated by estimating a sitewide average residual surface sediment concentration. Table 12-3 presents the sitewide residual concentrations for each alternative. The performance of each alternative to achieve PRGs for RAO 1 is assessed by estimating relative progress towards those PRGs from mean baseline conditions (i.e., sitewide average residual concentrations under No Action) for each risk-driver COC. Table 12-2 summarizes these performance percentages and Table 12-3 presents a summary of how each alternative complies with the PRG for each RAO. Alternative 2A4c, conventional capping to the study area boundary, meets RAO 1 PRGs for all COCs. Other containment-focus alternatives do not meet RAO 1 PRGs at the end of construction for total PCBs, lead, and cPAHs but would provide incremental risk reduction and achieve 76 percent to 100 percent progress towards reaching RAO 1 PRGs from mean baseline conditions. All containment-focus alternatives meet the RAO 1 PRG for copper and TBT. All containment-focus alternatives meet the RAO 1 PRG for arsenic, except Alternatives 2A1 and 2A4a.

All containment-focus alternatives meet PRGs associated with RAOs 2, 3, and 4 at the end of construction by achieving a cumulative risk of $\leq 1 \times 10^{-5}$ (netfishing, tribal clamming, and assumed beach play areas), meeting SQS, and achieving hazard quotients of less than 1 for the remaining sediment exposure scenarios (Table 12-2).

Magnitude of Subsurface Residual Risks

The magnitude of subsurface residual risks was qualitatively gauged by evaluating the re-exposure potential from the sediment cores with concentrations above SMS criteria and located within the remediated areas. The sediment cores in the FS data set with concentrations above the SQS and CSL after remediation and that are located within areas to be capped or undergo ENR for each containment alternative are grouped according to their depth below the surface (either less than or greater 3 feet below surface; Table 12-4). Subsurface residual concentrations in those cores are shown in Figure 12-2, which presents the sediment concentrations for the risk-driver COCs that remain at the RI sampling locations and the approximate depth in the underlying sediment below the post-remedy construction mudline surface prior to cap or ENR layer placement.

Based on the FS sediment core data set, Alternatives 2A4a, 2A4b, and 2A4c would not leave any contamination with CSL or SQS exceedances at less than 3 feet depth over ENR areas. Alternative 2A2b would leave contamination with SQS exceedances detected in two cores located at less than 3 feet over ENR areas. Alternatives 2A1, 2A2a, 2A3, and 2B would leave subsurface contamination with CSL exceedance detected in two cores; with SQS exceedance detected in three to seven cores at less than 3 feet over ENR areas (Table 12-4). For these containment-focus alternatives, the re-exposure potential would be from the remaining sediment cores with SQS exceedances located in the top 3 feet of surface sediments. The re-exposure potential from the subsurface contamination remaining at ENR areas is less from the cores with CSL and SQS exceedances located deeper than 3 feet. Refer to Figure 12-2 for residual risk-driver contaminant concentrations compiled for Alternative 2A3, which is representative of the containment-focus alternatives.

Magnitude of Contaminant Mass Removal

Alternative 2B has a dredge component estimated to be 51,800 cy cubic yards (77,700 tons) to fit the 3-foot cap over the risk-driver surface sediment CSL footprint. Approximately 24.1 tons of contaminant mass (of copper, lead, arsenic, mercury, total PCBs, cPAHs, and TBT) would be removed after the dredging is complete. Removal of copper, lead, and arsenic contributes to most of the contaminant mass removal estimated (e.g., 16.2, 6.4, and 1.4 tons, respectively). The mass removal of other risk-driver COCs would be at a much smaller scale and within the range of 0.017 ton to 0.029 ton (see Table 11-5). A graphical illustration of the range of contaminant mass removals for Alternative 2B is provided in Section 13 where a comparative analysis was performed within all remedial alternatives.

The performance of the containment-focus alternatives would be monitored for 30 years as part of long-term O&M monitoring to verify that the remedial technologies are operating as intended. The monitoring program would identify whether there is any re-exposure; corrective measures such as repair of cap and ENR would be implemented as needed.

12.3.3.2 Adequacy and Reliability of Controls

All capped areas would satisfy ecological and human health RAOs because exposure to contaminated bed sediments by receptors of concern would be prevented. In Alternative 2B

(which contains a dredging component), capping/ENR will not be constructed until dredging is complete. Therefore, the cap surface would not be impacted by sediment resuspension that may occur during dredging.

Structural integrity of the capping system is expected to remain intact. As discussed in Section 6.1, studies of surface sediment dynamics due to hydrodynamic forces exerted on bottom sediments suggest that the overall potential for movement of site sediments is low based on the calculated near-bottom shear stress values for the study area. The bathymetric survey conducted in 2006 (Tetra Tech, 2006) also suggests minimal erosion and redistribution processes at the Lockheed West Site. Seismic analysis findings indicated that excessive deformation and ground movement intersecting contaminated sediments is unlikely in the project site footprint for nominal 100-year event, and likely for 500-year and 2,500-year events. When ground movement intersecting contaminated sediments is predicted, lateral displacements and sediment movements would be such that corrective measures, such as cap repair and/or replacement, would be feasible (Section 6.1 and Appendix H). Based on the liquefaction-induced deformation analysis, there exists a risk of potential upwelling, exposure, and spreading of contaminated sediments beneath the capped areas due to liquefaction; however, the hazard is expected to be localized and remain within the dry dock hot spot area. Such an event may cause short-term disruption to the benthic community in the affected zone, which could then be repaired by placement of additional cap material. In the ENR areas, the concentrations in the subsurface sediments are relatively low (below SQS) with only limited and localized exceedances present (Figure 12-2). Impacts from seismic events in the ENR areas may require some repair actions. The long-term O&M monitoring program will verify long-term stability and performance of the cap, including the need for any repair.

All containment-focus alternatives require an institutional controls plan of similar scope and duration because the PRGs for RAO 1 cannot be achieved (except for Alternative 2A4c) and the subsurface contaminated sediment above protective levels remains in place. The institutional controls include:

- Seafood consumption advisories, public outreach, and education apply sitewide;

- Proprietary controls, monitoring and notification of waterway users, enforcement and permit tools and site registry apply to cap areas (see Section 12.3.1).

Community information/education, fish and/or shellfish consumption advisories and related signage, and vessel operations/anchorage restrictions are technically implementable for the Lockheed West Site. The administrative implementability of some institutional controls such as restricted anchorage and navigation zones within federal and state waterways will be discussed with the Tribes, because the Site is a tribal U&A area, and with other agencies having jurisdiction in the area. The administration of these institutional controls would require the cooperation of the implementing agencies and local Native American tribes, as well as public acceptance and commitment from the public, site users, and site owners. Refer to Section 10.4 for detailed discussion of effectiveness and implementability of institutional controls.

The scale of institutional controls in terms of notification of waterway users (i.e., identification of cap areas as restricted anchoring zones) and restrictive covenants (i.e., controls to prevent or limit the owners from conducting an activity that could result in the exposure of buried contamination to the environment) will increase based on the proposed cap area. These controls also raise the issue of future use restrictions of cap areas (e.g., diminishment of commerce and navigation). In this context, Alternative 2A4c (i.e., capping to the study area boundary) has the largest scale of future use restrictions compared to the other containment-focus alternatives. Institutional control costs associated with restriction to future use were accounted for in the cost estimates; however, any cost associated with a third-party settlement fee for future use restrictions in commerce and navigation due to capping was not included. Future use restrictions were incorporated into the detailed and comparative evaluation of the alternatives against the NCP's threshold and primary balancing criteria. As noted in Section 10.4, the intent of the remedial design is to minimize institutional controls and not to impact or restrict future aquatic land use and/or tribal treaty rights.

The combination of monitoring, maintenance, and institutional controls; formal 5-year reviews; and contingency actions (if required) is considered adequate for ensuring remedy integrity. As a whole, these devices will enable the remedial alternatives to be adaptively managed, as needed, based on new information.

12.3.4 Reductions in Toxicity, Mobility, or Volume through Treatment

There would be no reduction of toxicity, mobility, or volume through treatment with the containment-focus alternatives because no treatment would be implemented. Reduction in toxicity, mobility, and volume would occur through physical isolation of the most contaminated sediment and natural recovery processes that are ongoing at the Site.

12.3.5 Short-term Effectiveness

Minimal short-term risks would occur as a result of implementing the containment-focus alternatives. Some resuspension of sediment is inevitable during material placement. Depending on the degree of resuspension, a short-term increase in bioavailability of COCs may occur. However, the temporary increase in COCs would be offset by the reduction in contaminant concentrations in surface sediment. Sediment placement would present a risk to workers due to the usual physical hazards from working over water and operating heavy equipment. Potential physical hazard risks and risks to Site workers from exposure to contaminants and operational hazards such as light, noise, and air emissions would be mitigated by the use of personal protective equipment as specified in the health and safety plan and through the use of appropriate equipment and material handling procedures, to be specified in the design documents and the work plans. Sitewide monitoring and sampling activities will be relatively infrequent and less intrusive than remedial construction activities and so are expected to pose negligible potential risk to site workers.

Alternative 2B includes dredging to fit the cap to minimize changes to water depth (Figure 11-10). Resuspension of contaminated sediment is inevitable during environmental dredging operations. Dredged material resettles primarily onto the dredged surface and areas just outside the dredge footprint and fine-grained material that is slow to resettle can be transported beyond the dredge operating area. Dredging also releases contaminants into the dissolved phase (i.e., the water column). Release of contaminated sediment that settles back onto the dredged surface or to areas just outside the dredge footprint, as well as any residual left after dredging, is assumed to be managed through application of a cover backfill (i.e., a nominal 9-inch layer of sand with the goal of achieving a minimum 6-inch layer of sand) over the dredge footprint.

Environmental impact evaluation also includes habitat disturbance, consumption of natural resource materials (e.g., for capping), landfill capacity utilization, transportation mileage, particulate matter, and gas emissions as recommended by EPA Region 10's Clean and Green Policy (EPA, 2009f, 2010b). Environmental impacts to habitat are measured as the amount of active remediation in intertidal and shallow subtidal areas above -10 feet MLLW. Shoreline/intertidal remediation and habitat improvement is a common element for all containment-focus remedial alternatives, which includes partially dredging to 3 feet below the mudline followed by backfilling with sand to approximate pre-existing grades over an approximately 2-acre area. The habitat areas would be improved by placement of habitat mix, riparian plantings, and other habitat features with the goal of no net loss of intertidal habitat. Further provisions to improve upon the existing habitat would be considered during remedial design.

Local transportation impacts (traffic, noise) from implementation of these alternatives are proportional to the number of truck/train miles estimated for support of material hauling operations (Appendix G). All containment-focus alternatives, except Alternative 2B which also includes hauling of 51,800 cubic yards of dredged material, have the same total truck/train miles to haul dredged material removed during the former shipway and shoreline/intertidal remediation (Table G-1). The particulate matter (PM_{10}) generated from all combustion activity is estimated to be in the range of 1.5 long tons (Alternative 2A1) to 11.9 long tons (Alternative 2B) (Table G-1). The CO_2 generated from all combustion activity is estimated to be in the range of 1,045 long tons (Alternative 2A1) to 2,796 long tons (Alternative 2A4c) (Table G-2). As recommended by EPA Region 10's Clean and Green Policy (EPA, 2009f), possible sustainable best management practices that could be applied to all the remedial alternatives for minimizing the carbon footprint during construction are identified and summarized (see Appendix G).

12.3.6 Implementability

The implementability of the containment-focus alternative is addressed through individual assessment of the technical feasibility of its technology components.

12.3.6.1 Capping/ENR Component – Alternatives 2A1, 2A2a, 2A2b, 2A3, 2A4a, 2A4b, 2A4c, and 2B

Existing bathymetric site profiles generated from a survey using high-resolution multibeam sonar show uneven topography of seafloor surface (Appendix E). The placement of sediment caps over the slopes represents a technical challenge greater than the placement over relatively flat bottoms. Existing seafloor slopes are mostly at about a 1 vertical to 3 horizontal ratio (approximately 17 degrees), while some slopes are flatter and some slopes are close to a 1 vertical to 2 horizontal ratio (approximately 26 degrees). The challenge of placing cap material on such slopes can be overcome by careful selection of a cap material with sufficient strength (e.g., higher percentage of coarse/medium grained sand material in the grain size distribution) and by devising a method to place the cap to maintain its stability. This can be accomplished by scheduling the placement starting at the toe of the slope, using a toe berm when necessary, and building upward. Another technical challenge is that the design of cap material grain size distribution should be such that a newly placed cap would not be susceptible to liquefaction during a seismic event. The cap thickness should also be designed not only for isolation but also to minimize or eliminate future site use restrictions related to tribal treaty rights.

Environmental considerations, such as protection of fish migration windows, climate, weather, hydraulic, and hydrologic conditions, can be incorporated into the capping design, implementation, and schedule. A monitoring and maintenance program can also be established to verify that such effects (if and when they occur) do not reduce the remedial design intent of the cap and repairs can be implemented to rectify any damage. The success of a capping remedy is verifiable. Bathymetric and topographic surveys can be used to verify the thickness of the cap and post-removal action confirmation samples from the cap surface can be analyzed to verify that contaminated sediment is isolated from the water and biota. Sediment profile imaging can also provide better understanding of benthic community dynamics to verify the success of a cap. Capping is considered a technically mature and reliable technology that is feasible for this alternative. The technical difficulties of capping can be addressed by design and logistical means during design.

12.3.6.2 Dredging Component – Alternative 2B

Alternative 2B includes a dredging component for removing sediments to fit the 3-foot conventional cap with the goal of minimizing changes to existing water depths.

Technologies associated with the handling, transportation, and off-site disposal of dredged sediment are all considered technically feasible and proven technologies that have been implemented at several contaminated sediment remediation projects in the Pacific Northwest. Incidental technologies, such as dewatering and the treatment and discharge of the treated decant water, are also considered technically feasible, proven technologies.

Two regional Subtitle D landfills (Allied Waste Inc., in Roosevelt, Washington, and Waste Management in Arlington, Oregon) that are both permitted to receive wet sediment (i.e., sediment that does not pass the paint filter test) are selected in this FS as the upland disposal facilities for removal alternatives. Refer to Section 11.3 on implementation of common remedy elements of removal such as residuals management, dredge water management, transloading, and upland disposal.

Environmental considerations such as fish windows, climate, weather, hydraulic, and hydrologic conditions can be incorporated into the dredging design and implementation schedule. The success of dredging can be verified through multiple methods, including real-time surveys, bathymetric surveys, and sediment sampling. Construction quality assurance/quality control and monitoring activities are designed to verify the performance of dredging.

Dredging is considered a technically mature and reliable technology that is feasible for Alternative 2B. The technical difficulties of dredging can be addressed by design and logistical means during design and implementation.

With respect to administrative feasibility, dredging will require substantive compliance with Sections 404 and 401 of the Clean Water Act and ESA consultation. All generator requirements related to the off-site transport and disposal of the dredged material should be met. Agreements with the Port will be necessary to coordinate all work (e.g., access to Port property, security requirements for waters adjacent to Port facilities, and compliance with Transportation Worker

Identification Credential requirements). Transloading facility operations and upland disposal should also be coordinated with truck and train schedules.

Resources for the removal technology are available from multiple vendors and procurable through competitive bidding. There are numerous marine contractors, suitable construction equipment, and sufficient skilled labor in the Pacific Northwest and along the West Coast to execute a contaminated sediment removal project.

12.3.7 Cost

The FS-level estimated total cost to implement Alternative 2 ranges from $17.0 to $43.8 million as the scale of active remediation increases. Institutional control costs associated with future use restrictions of capped areas were incorporated into the cost estimates; however, potential third-party settlement costs were recognized but not taken into account in the cost estimates. Institutional control costs are acknowledged to emphasize the importance of considering appropriate types of institutional controls that give reasonable assurance that the Site remedy remains protective over time while being consistent with the Site's future use to minimize the indirect costs. While the intent of the remedial design is to minimize both institutional controls and impacts or restrictions to future aquatic land use and/or tribal treaty rights, any future use restrictions were considered in the detailed and comparative evaluation of the alternatives in this section and Section 13. Table 12-2 summarizes cost information for each containment-focus alternative and Appendix F provides detailed cost estimates.

12.4 DETAILED ANALYSIS OF ALTERNATIVE 3: REMOVAL-FOCUS

The removal-focus Alternative 3 would dredge the most impacted sediments, dispose of the sediments off-site, and contain risk-driver COCs in removal areas and in all remaining areas by conventional cap or ENR where risk-driver COC concentrations are greater than RALs. This general alternative includes four subalternatives (3A1, 3A2, 3B, and 3C) referred as removal-focus alternatives and would actively remediate about 30 acres through a combination of dredging, capping, and ENR (Figure 12-3). Table 12-2 presents the technology application areas, scope, performance, and cost summaries for the removal-focus alternative.

12.4.1 Overall Protection of Human Health and the Environment

The removal-focus Alternative 3 would provide incremental risk reduction for RAO 1 by making progress toward PRGs and utilizing institutional controls and achieving PRGs associated with RAOs 2, 3, and 4 immediately following construction. The removal-focus alternatives are estimated to be completed in one construction season, except for Alternative 3C under which in-water construction activities may require two construction seasons to complete. Estimated time to achieve RAOs is at the completion of construction.

The contaminant mass would be removed through dredging (38 metric tons for Alternative 3A1, 51 metric tons for Alternative 3A2, 60 metric tons for Alternative 3B, and 91 metric tons for Alternative 3C). None of the removal-focus alternatives can achieve RAO 1 for the seafood consumption scenario but they do provide substantial progress towards reaching RAO 1 PRGs (e.g., 93 percent to 95 percent) from mean baseline conditions (Tables 12-2 and 12-3). At the end of construction, the remedies produce a clean surface over the areas remediated, achieving the PRGs for all RAOs in the short term. Over the long term, the surface and near surface sediments will reach an equilibrium concentration through mixing as described for ENR application at the Site. Some deposition of new sediment over the post-construction surface is expected to occur. The long-term concentrations for COCs at the Site are expected to fall between the natural background levels and the concentrations found in the Elliott Bay region. Institutional controls including programs of advisories, outreach, and education are implemented to reduce seafood consumption exposures to achieve RAO 1. Long-term O&M monitoring is designed to assess recovery processes and long-term human health risk reduction.

Specific institutional controls potentially applicable to the cap areas of each removal-focus alternative include the following:

- Governmental controls (i.e., monitoring and notification of waterway users):
  - Restrictive anchorage within the areas that are capped;
  - Restrictive grounding of small vessels on the shoreline;
  - Restrictions of vessel draft, horsepower, speed, and time in area; and
  - Restrictions on piling placement or removal through cap, or special maintenance requirements;

- Proprietary controls (i.e., easements and restrictive covenants related to cap);
- Enforcement and permit tools (i.e., administrative orders, consent decrees); and
- Informational devices (i.e., seafood consumption advisories, education and public outreach, and site registry).

Specific institutional controls applicable to dredge, ENR, and unremediated areas within the study area boundary for each removal-focus alternative include the following:

- Informational devices such as education and public outreach, and seafood consumption advisories.

Of the institutional controls potentially applicable to cap areas listed above, any restrictions on anchorage and grounding of tribal vessels will be minimized during design because the Site is a tribal U&A area; however, all of the institutional controls were considered during the detailed evaluation of remedial alternatives in this FS.

The dredge areas of removal-focus alternatives may also require short-term fish consumption advisories due to short-term impacts during remedial construction when the highest sediment contaminant concentrations are being actively dredged. Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations are higher for the removal-focus alternative than the containment-focus alternative and increase with increased removal quantities and associated activities (e.g., transloading and transportation). Protection of workers and the community from physical injury are manageable with appropriate planning and standard construction practices. Institutional controls are required to protect consumers of resident seafood during construction.

The potential for re-exposure of subsurface contaminated sediment following active remediation is considered low and would be primarily from areas dredged and managed by ENR. Alternative 3A2 would leave subsurface contamination with SQS exceedances (detected in four sediment cores) and no CSL exceedance in the top 3 feet of sediments over ENR areas; Alternatives 3A1, 3B, and 3C would leave contamination with CSL exceedance (detected in two cores) and SQS exceedances (detected in seven cores) at the same level in the top 3 feet of sediment over ENR areas. Re-exposure potential from remaining subsurface contamination over dredged areas is expected to be similar in scale for all removal-focus alternatives (Table 12-4).

For all removal-focus alternatives, re-exposure of subsurface contaminated sediment is likely to be localized and have limited effect on sitewide averages and to the protectiveness of the remedy, which will be monitored over a 30-year period. Refer to Section 12.1.2.1 for additional discussion of the long-term effectiveness and permanence of all alternatives.

Long-term monitoring, maintenance, and institutional controls are required and are considered to be reliable for removal-focus alternatives. The scope of monitoring and maintenance for capping is at about same scale for Alternatives 3A1, 3A2, and 3B because the conventional capping areas are very close (i.e., 5.4 acres vs. 6.3 acres), while Alternative 3C has substantially less (only about 1 acre of conventional capping). The scope of monitoring and maintenance for ENR is about at the same scale for all removal-focus alternatives. Institutional control programs for all Alternative 3 subalternatives are of similar scope and duration.

12.4.2 Compliance with ARARs

Removal-focus alternatives are expected to comply with ARARs at the end of construction except as follows:

- The removal-focus alternatives have the same limitations as the containment-focus alternatives. The alternatives are unlikely to achieve the RAO 1 PRGs for human seafood consumption. These PRGs are based on natural background, and it is not practicable to achieve natural background concentrations for these contaminants at the Lockheed West Site. Compliance with the MTCA ARARs is achieved by reducing concentrations and by using institutional controls designed to reduce human exposure to resident fish and shellfish.
- Surface water quality at the Lockheed West Site is expected to improve as a result of sediment remediation but not expected to achieve all ARARs. Compliance with some water quality standards may not be feasible, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs, and due to uncontrolled in-water sources.

Waivers of ARARs based on technical impracticability may be required for one or more of the above conditions depending on what cleanup levels are established in the remedy decision documents and on long-term monitoring results.

The level of performance achieved by all removal-focus alternatives, for FS evaluation purposes, is determined to be sufficient for achieving PRGs associated with RAOs 2 through 4 (Table 12-2).

12.4.3 Long-Term Effectiveness and Permanence

General analysis factors considered during detailed evaluation of alternatives for long-term effectiveness and permanence are magnitude of residual risks and adequacy and reliability of controls.

12.4.3.1 Magnitude of Residual Risks

The remedial alternatives were evaluated for three types of residual risk: surface and subsurface residual contamination and contaminant mass removal.

Magnitude of Surface Sediment Residual Risks

The magnitude of surface contamination remaining under the removal-focus alternatives was evaluated by estimating a sitewide average residual surface sediment concentration. Table 12-3 presents sitewide residual concentrations for each alternative. The performance of each alternative to achieve PRGs for RAO 1 is assessed by estimating relative progress towards those PRGs from mean baseline for each COC. Table 12-2 summarizes these performance percentages and Table 12-3 presents a summary of how each alternative complies with each RAO PRG. All removal-focus alternatives meet RAO 1 PRGs for arsenic, TBT, and copper. The alternatives do not meet RAO 1 at the end of construction for total PCBs, lead, and cPAHs but achieve 76 percent to 94 percent towards reaching RAO 1 PRGs for these compounds from mean baseline.

All removal-focus alternatives meet RAO 2, 3, and 4 PRGs by achieving a cumulative risk equal to or less than 1×10^{-5} (netfishing, tribal clamming, and assumed beach play areas), meeting SQS, and achieving a hazard quotient for the remaining direct sediment exposure scenarios of less than 1 (Table 12-2).

Magnitude of Subsurface Residual Risks

Similar to the detailed evaluation of containment-focus alternatives, the magnitude of residual risks was also qualitatively gauged by evaluating the re-exposure potential from the remaining

sediment cores with concentrations above SMS criteria and located within the remediated areas. The number of sediment cores in the FS data set with concentrations above SQS and CSL that would remain after remediation and are located within areas that are dredged, capped, or undergo ENR for each removal-focus alternative are grouped in depths of less than and greater than 3 feet (Table 12-4). Subsurface residual concentrations in those cores are shown in Figures 12-4 through 12-7. These figures present the sediment concentrations for the risk-driver COCs that remain at the RI sampling locations after the remedy is constructed for Alternatives 3A1, 3A2, 3B, and 3C prior to dredge backfill, cap, or ENR layer placement.

Re-exposure potential from the deeper cores (i.e., deeper than 3 feet) is lower than the cores with exceedance concentrations in the upper 3 feet. As discussed in Section 12.1.2, the potential for recontamination from disturbance mechanisms generally decreases with the depth of contamination and as the surface area containing subsurface contamination decreases. Re-exposure potential from the capped areas is also unlikely because the cap system would be engineered to ensure isolation and permanence. Mechanisms for re-exposing subsurface sediment from cap areas include high-flow scour, propeller wash, construction activities, and seismic events. The cap will be designed to minimize disturbances from man-made activities; however, the structural integrity of the cap may be affected by a seismic event. The findings of the seismic study indicate that excessive deformation and ground movement intersecting contaminated soils is unlikely for a nominal 100-year event. Consistent with the evaluation approach outlined in Section 12.1.2, the re-exposure potential from the capped areas is considered less than that from the dredge and ENR areas.

The re-exposure potential from the dredged and ENR areas presents a slightly higher risk than the capped areas. This higher risk is because the residual management measures at dredged areas (i.e., backfill with 9 inches of sand layer to ensure 6-inch coverage) and ENR do not perform as an isolation cap. Alternatives 3A1, 3B, and 3C would leave a similar level of subsurface contamination with CSL and SQS exceedances within the top 3 feet of sediments over the footprint of dredged and ENR areas (no cores in dredged area with CSL exceedance, three to four cores in ENR areas with CSL exceedance, and four to five cores in ENR areas with SQS exceedance). Under Alternative 3A2, re-exposure potential from subsurface contamination is expected to be slightly lower than Alternatives 3A1, 3B, and 3C (one core with CSL exceedance

over dredged area; two and three cores with SQS exceedance over dredged and ENR areas in the top 3 feet of sediments). Table 12-4 presents the detailed metrics. The potential for re-exposure of subsurface contaminated sediment under removal-focus alternatives is considered low and would be primarily from the cores with CSL and SQS exceedances located within the top 3 feet of sediments over the footprint of dredged and ENR areas.

Magnitude of Contaminant Mass Removal

The removal-focus alternatives provide 38 to 91 metric tons of contaminant mass removals of risk-driver COCs through dredging 55,500 to 148,500 cubic yards of contaminated sediments. Removal of copper, lead, and arsenic contributes to most of the contaminant mass removal (e.g., in the range of 3.1 to 56.5 tons). The mass removal of other risk-driver COCs (i.e., total PCBs, cPAHs, mercury, and TBT) would be on a much smaller scale and within the range of 0.043 ton to 0.146 ton. Table 11-5 presents contaminant mass removal quantities for removal-focus alternatives and Figures 12-8a and 12-8b illustrate them.

12.4.3.2 Adequacy and Reliability of Controls

All removal-focus alternatives provide incremental risk reduction for RAO 1 PRGs and achieve RAO 2, 3, and 4 PRGs immediately following construction. Alternative 3A2 has the largest dredge area of 18 acres compared to other removal-focus alternatives, thereby requiring a proportionately larger effort to manage dredging residuals. Alternative 3C has the largest dredge volume of 148,500 cubic yards and requires a larger effort for material handling, dredge water management, transporting, and upload disposal. Alternatives 3A1, 3A2, and 3B have slightly broader scope and higher long-term monitoring and maintenance requirements than Alternative 3C based on the surface areas remediated by capping and ENR.

Post-removal action confirmation sampling and analysis will be conducted after construction to provide direct measurement of residual conditions. Corrective actions will be taken if conventional cap areas or dredged areas fail to meet performance requirements.

The capping component of the alternatives will not be constructed until dredging is complete. Therefore, the cap surface would not be impacted by sediment resuspension that may occur during dredging. The structural integrity of the cap may be affected by a seismic event. Seismic analysis findings indicated that excessive deformation and ground movement intersecting

contaminated soils is unlikely for nominal 100-year event, but likely for 500-year and 2,500-year events. The seismic-induced lateral displacements and sediment movements would be such that corrective measures, such as cap repair and/or replacement, would be feasible. Based on the liquefaction-induced deformation analysis, upwelling, exposure, and spreading of contaminated sediments beneath the capped areas due to liquefaction may occur; however, the hazard is expected to be localized and remain within the dry dock hot spot area. Such an event may cause short-term disruption to the benthic community in the affected zone, which could then be repaired by placement of additional cap material (see Section 6.1 and Appendix H). In the ENR areas, the concentrations in the subsurface sediments are relatively low (below SQS) with only limited and localized exceedances present (Figures 12-4 through 12-7). Impacts from seismic events in the ENR areas may require some repair actions. A long-term O&M monitoring program will verify long-term stability and performance of the cap areas, as well as the need for any repair.

All removal-focus alternatives require an institutional controls plan of similar scope and duration because the PRGs for RAO 1 cannot be achieved and some subsurface contaminated sediment above protective levels remains in place. The institutional controls include:

- Seafood consumption advisories, public outreach, and education, which apply sitewide; and
- Proprietary controls, monitoring and notification of waterway users, enforcement and permit tools, and site registry, which apply to cap areas (see Section 12.4.1).

The scale of institutional controls regarding notification of waterway users and restrictive covenants is about the same for Alternatives 3A1, 3A2, and 3B where the proposed cap areas are very close (i.e., 5.4 acres vs. 6.3 acres) but substantially less for Alternative 3C, which has only about 1 acre of conventional capping. The similar analogy is applicable for the future use restrictions. Alternative 3C has the least future use restrictions compared to the other removal-focus alternatives.

The combination of monitoring, maintenance, and institutional controls; formal 5-year reviews; and contingency actions (if required) is considered adequate for ensuring remedy integrity

12.4.4 Reductions in Toxicity, Mobility, or Volume through Treatment

As discussed in Section 12.3.4, there would be no reduction of toxicity, mobility, or volume through treatment with the removal-focus alternatives, because no treatment would be implemented, although there is a reduction of volume and mobility from these remedies.

12.4.5 Short-term Effectiveness

Sediment removal and placement would present a risk to workers due to the usual physical hazards from working on a dredge and operating heavy equipment. Similar to the containment-focus alternatives (see Section 12.3.4), potential physical hazard risks and risks to Site workers from exposure to contaminants and operational hazards would be mitigated by the use of personal protective equipment as specified in the health and safety plan and through the use of appropriate equipment and material handling procedures, to be specified in the design documents and the work plans. General short-term physical hazards include construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations at levels higher than for the containment-focus alternatives, which would increase with increased removal quantities and associated activities (e.g., transloading and transportation). As discussed in Section 12.1.2.3, dredging projects show a trend of elevated fish tissue concentrations during dredging activities, followed by a decline shortly after remediation is completed, typically within 1 year or less (WDNR, 2011).

Environmental impacts includes habitat disturbance, consumption of natural resource materials (e.g., for capping), landfill capacity utilization, transportation mileage, and gas emissions. Environmental impacts to the habitat are correlated with the shoreline/intertidal remediation and habitat improvement, a common element for remedial Alternatives 2, 3, and 4, and discussed in detailed evaluation of Alternative 2 (see Section 12.3.4).

Local transportation impacts (e.g., traffic and noise) from implementation of these alternatives are proportional to the number of truck loads/train miles estimated for support of material hauling operations and increases as the proposed dredge volume increases (Alternative 3A: 40,000/12,000; Alternative 3A2: 80,000/23,000; Alternative 3B: 60,000/18,000; Alternative 3C: 96,000/28,000). The PM_{10} generated from all combustion activity is estimated to be in the range of 12.2 long tons (Alternative 3A1) to 30.1 long tons (Alternative 3C) (Table G-1). The CO_2

generated from all combustion activity is estimated to be in the range of 2,230 long tons (Alternative 3A1) to 4,030 long tons (Alternative 3C) (Table G-2). As recommended by EPA Region 10's Clean and Green Policy (EPA, 2009f), possible sustainable best management practices that could be applied to all the remedial alternatives for minimizing the carbon footprint during construction are identified and summarized (see Appendix G).

12.4.6 Implementability

Both dredging and capping are considered technically mature and reliable technologies feasible for removal-focus alternatives. The technical difficulties of dredging and capping can be addressed by design and logistical means during design and implementation. Refer back to Section 12.3.6 for detailed implementability discussion of dredging and capping components of removal-focus alternatives.

12.4.7 Cost

Table 12-2 summarizes the cost information and Appendix F provides detailed cost estimates. The FS-level estimated total cost to implement Alternative 3 is in the range of $28.9 to $47.0 million, increasing as the scale of active removal remediation increases. Potential costs associated with the future use restrictions of capped areas (i.e., in the range 1.3 to 6.3 acres for removal-focus alternatives) were recognized but not taken into account during this evaluation process. Such costs are acknowledged for the applicable alternatives to emphasize the importance of considering appropriate types of institutional controls that give reasonable assurance that the Site remedy remains protective over time while being consistent with the future site use to minimize the indirect costs.

12.5 DETAILED ANALYSIS OF ALTERNATIVE 4: COMPLETE REMOVAL

Alternative 4 would dredge all sediments within the Lockheed West Site where risk-driver COC concentrations are greater than RALs within the area of potential action footprints, with off-site disposal of sediments. This complete removal alternative includes three subalternatives (4A, 4B, and 4C) referred as complete removal alternatives and would actively remediate about 18, 30, or 40 acres depending on the area of potential action footprint (Figure 12-9). Table 12-2 presents the technology application areas, scope, performance, and cost summaries.

12.5.1 Overall Protection of Human Health and the Environment

The Alternative 4 complete removal alternatives would provide incremental risk reduction for RAO 1 PRGs (i.e., progress towards reaching RAO 1 PRGs from mean baseline), and achieve PRGs associated with RAOs 2, 3, and 4 immediately following construction. The complete removal alternatives have an estimated construction period of 3 to 9 years. The estimated time to achieve RAOs is at the completion of construction.

Complete removal alternatives would achieve greater contaminant mass removal compared to the other alternatives (i.e., 137 metric tons for Alternative 4A, 181 metric tons for Alternative 4B, and 195 metric tons for Alternative 4C). Alternative 4C can achieve the RAO 1 PRGs. Alternatives 4A and 4B can provide incremental risk reduction and progress towards meeting RAO1 PRGs compared to mean baseline conditions (i.e., 95 percent and 97 percent, respectively). Under Alternative 4C, no institutional controls would be implemented to further reduce seafood consumption exposures to achieve RAO 1.

Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations are highest compared to Alternatives 2 and 3, and increase with increased removal quantities. Protection of workers and the community from physical injury is manageable with appropriate planning and standard construction practices. Institutional controls would likely be required to protect consumers of resident seafood during construction.

Complete removal alternatives 4B and 4C would not leave any subsurface contaminated sediment with concentrations above SMS criteria; therefore, the re-exposure potential following active remediation is expected to be negligible. Under the Alternative 4A scenario, the potential from re-exposure of subsurface contaminated sediment is considered very low and would potentially be from the two isolated sediment cores with SQS exceedances that remained in the top 3 feet of sediments. Long-term O&M monitoring would be required in the implementation of Alternatives 4A and 4B but not for Alternative 4C due to removal of all subsurface contamination and the post-remedy residual surface concentrations meeting all RAO PRGs. The alternatives would not restrict any potential future uses associated with navigation and commerce.

Specific institutional controls applicable to dredge and unremediated no action areas for Alternatives 4A and 4B within the study area boundary include informational devices such as education and public outreach and seafood consumption advisories.

Complete removal alternatives may also require short-term fish consumption advisories due to short-terms impacts during remedial construction when the highest sediment contaminant concentrations are being actively dredged. Complete removal alternatives are further evaluated for their overall protectiveness of human health and the environment through the long-term effectiveness and permanence and short-term effectiveness criteria evaluations provided below.

12.5.2 Compliance with ARARs

Complete removal alternatives have similar limitations as the containment-focus and removal-focus alternatives. Alternatives 4A and 4B are unlikely to achieve the RAO 1 PRGs for human health seafood consumption that are based on natural background. Although Alternative 4C achieves RAO 1 PRGs within a defined study area (if a vertical boundary could be defined), it is generally not practicable to achieve natural background concentrations for these contaminants at the Lockheed West Site. Compliance with the MTCA ARARs (meeting natural background concentrations for RAO 1 PRGs) is achieved by reducing concentrations and by using institutional controls designed to reduce human exposure to resident fish and shellfish.

Surface water quality at the Lockheed West Site is expected to improve as a result of sediment remediation but is not expected to achieve all ARARs. The level of performance achieved by all removal alternatives, for FS evaluation purposes, is determined to be sufficient for achieving RAOs 2, 3, and 4. Table 12-2 provides a summary of ARAR compliance for the removal alternatives.

12.5.3 Long-Term Effectiveness and Permanence

As in Sections 12.3.3 and 12.4.3, general analysis factors considered during detailed evaluation of alternatives for long-term effectiveness and permanence are magnitude of residual risks and adequacy and reliability of controls.

12.5.3.1 Magnitude of Residual Risks

The remedial alternatives were evaluated for three types of residual risk: surface and subsurface residual contamination and contaminant mass removal.

Magnitude of Surface Sediment Residual Risks

The magnitude of surface contamination remaining under removal-focus alternatives was evaluated by estimating a sitewide average residual surface sediment concentration. Table 12-3 presents the sitewide residual concentrations for each alternative. The performance of each alternative toward reaching PRGs for RAO 1 is assessed by estimating the relative progress towards reaching RAO 1 PRGs from the mean baseline for each COC. Table 12-2 summarizes these performance percentages and Table 12-3 presents a summary of how each alternative complies with each RAO PRG. Alternative 4C meets the RAO 1 PRGs. Complete removal Alternatives 4A and 4B meet RAO 1 PRG for arsenic, TBT, and copper. The alternatives do not meet RAO 1 for total PCBs, lead, and cPAHs but achieve 88 percent to 92 percent towards reaching RAO 1 PRGs from the mean baseline.

All removal alternatives meet PRGs associated with RAOs 2, 3, and 4 by achieving a cumulative risk equal to or less than 1×10^{-5} (netfishing, tribal clamming, and assumed beach play areas), meeting SQS, and achieving a hazard quotient for the remaining direct sediment exposure scenarios of less than 1 (Table 12-2).

Magnitude of Subsurface Residual Risks

Similar to the detailed evaluation of containment and removal-focus alternatives, the magnitude of residual risks can be qualitatively gauged by evaluating the re-exposure potential from the sediment cores that remain with concentrations above SMS criteria and located within the remediated areas. The number of sediment cores in the FS data set with concentrations above SQS and CSL and that would remain after remediation for each removal alternative are grouped in depths of less than and greater than 3 feet (see Table 12-4). Alternatives 4C would not leave any subsurface contamination with concentrations above SMS criteria following active remediation and therefore, no re-exposure potential is expected. There would be four and two isolated sediment cores with SQS exceedances at less than 3 feet depth in unremediated areas that would remain under Alternatives 4A and 4B. The potential for re-exposure of subsurface

contaminated sediment under Alternatives 4A and 4B are considered very low and would be primarily from those cores with SQS exceedances.

Magnitude of Contaminant Mass Removal

Complete removal alternatives provide 137 to 195 metric tons of contaminant mass removal of risk-driver COCs through dredging of 342,000 to 1,214,300 cubic yards of contaminated sediments. Removal of copper, lead, and arsenic contributes to most of the contaminant mass removal (in the range of 11.4 to 117.5 tons). The mass removal of other risk-driver COCs (total PCBs, cPAHs, mercury, and TBT) would be on a much smaller scale and within the range of 0.087 ton to 0.310 ton. Contaminant mass removal quantities for complete removal alternatives are presented in Table 11-5 and illustrated in Figures 12-10a and 12-10b.

12.5.3.2 Adequacy and Reliability of Controls

Complete removal alternatives would satisfy ecological and human health RAOs because exposure to contaminated bed sediments by receptors of concern would be prevented. Alternative 4C has the largest dredge area of 40 acres thereby requiring a proportionately larger effort to manage dredging residuals. Alternative 4C has also the largest dredge volume (1,214,300 cubic yards) and requires a larger effort for material handling, dredge water management, transporting, and upload disposal compared to Alternatives 4A and 4B. The construction duration of Alternative 4C is estimated as 9 years compared to 4A and 4B, which would require 3 and 6 years, respectively. Long-term O&M monitoring would be required for Alternatives 4A and 4B. Alternative 4C would not include long-term O&M monitoring requirements because it meets RAO 1 PRGs.

Post-removal action confirmation sampling and analysis will be conducted after construction to provide direct measurement of residual conditions. Corrective actions will be taken if dredged areas fail to meet performance requirements.

Alternatives 4A and 4B require institutional controls of sitewide seafood consumption advisories, public outreach, and education of similar scope and duration because the PRGs for RAO 1 cannot be achieved. Institutional controls regarding future site use restrictions and long-term protection of a capping system would not apply. Alternative 4C does not require any institutional controls.

12.5.4 Reductions in Toxicity, Mobility, or Volume through Treatment

As discussed above, there would be no reduction of toxicity, mobility, or volume through treatment with the complete removal alternatives, because no treatment would be implemented.

12.5.5 Short-term Effectiveness

Potential physical hazards to workers, community, and the environment during remedial actions are discussed in Sections 12.3.5 and 12.4.5. Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations from Alternative 4 are highest compared to Alternatives 2 and 3, and increase with increased removal quantities. Large dredging projects show the trend of elevated fish tissue concentrations during dredging activities, followed by a decline shortly after remediation is completed, typically within 1 year or less (WDNR, 2011). Local transportation impacts (e.g., traffic and noise) from implementation of these alternatives are proportional to the number of truck/train miles estimated for support of material hauling operations and increases as the proposed dredge volume increases (Alternative 4A: 212,000/61,000; Alternative 4B: 488,000/141,000; Alternative 4C: 735,000/212,000). The PM_{10} generated from all combustion activity is estimated to be in the range of 67.3 long tons (Alternative 4A) to 237 long tons (Alternative 4C) (Table G-1). The CO_2 generated from all combustion activity is estimated to be in the range of 7,823 long tons (Alternative 4A) to 26,712 long tons (Alternative 4C) (Table G-2). As recommended by EPA Region 10's Clean and Green Policy (EPA, 2009f), possible sustainable best management practices that could be applied to all the remedial alternatives for minimizing the carbon footprint during construction are identified and summarized (see Appendix G).

12.5.6 Implementability

Refer back to Section 12.3.6 for a detailed discussion of the implementability of dredging and residuals management components of the complete removal alternatives.

12.5.7 Cost

The FS-level estimated total cost to implement Alternative 4 is in the range of $92.3 to $302.8 million, increasing as the dredged area and volume increases. Table 12-2 summarizes cost information and Appendix F provides detailed cost estimates.

Table 12-1.
National Contingency Plan Evaluation Criteria for Detailed Analysis of Lockheed West Remedial Alternatives

Evaluation Criteria		FS Analysis Factors
Threshold Criteria	1. Overall Protection of Human Health and Environment 2. Compliance with ARARs	• How alternative provides human health and environmental protection
		• Compliance with chemical specific, location specific, and action specific ARARs • Compliance with other criteria, advisories, and guidance
Primary Balancing Criteria	3. Long-term Effectiveness and Permanence	• Magnitude of residual risks • Adequacy and reliability of controls
	4. Reductions in Toxicity, Mobility, and Volume Through Treatment	• Treatment process and remedy • Amount of hazardous material destroyed or treated • Reduction in toxicity, mobility, or volume • Irreversibility of the treatment • Type and quantity of treatment residual • Statutory preference for treatment as a principal element of remediation
	5. Short-term Effectiveness	• Protection of community during remedial actions • Protection of workers during remedial actions • Environmental impacts • Time until remedial action objectives are achieved
	6. Implementability	• Ability to construct and operate technology • Reliability of technology • Ease of undertaking additional remedial action if necessary • Monitoring considerations • Administrative feasibility • Availability of services and materials
	7. Cost	• Construction costs, equipment costs • Land and site development costs, disposal costs • Engineering expenses, license or permit costs • Contingency allowances • O&M costs
Modifying Criteria	8. State Acceptance	• State (Support Agency) technical and administrative issues and concerns
	9. Community Acceptance	• Public issues and concerns
Source: EPA, 1988		

Table 12-2. Remedial Alternatives – Scope, Costs, and Performance Summaries

		Alternative 1	Alternative 2								Alternative 3				Alternative 4		
		1	2A1	2A2a	2A2b	2A3	2A4a	2A4b	2A4c	2B	3A1	3A2	3B	3C	4A	4B	4C
Technology Application Summary																	
Actively Remediated Area (Acre)[1/]	Dredge	0	0	0	0	0	0	0	0	10.3	10.3	18	4	10.3	18	30	40
	Cap	0	10.3	10.3	18	10.3	18	30	40	10.3	5.4	5.4	6.3	1.3	0	0	0
	ENR	0	7.7	19.7	12	29.7	0	0	0	29.7	19.7	12	19.7	18.4	0	0	0
Former Shipway/Shoreline Remediation Area (Acre)		0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Total Actively Remediated Area[2/]		0	20	32	32	40	20	32	40	40	32	32	32	32	20	32	40
Dredge Volume (1,000 cy)[3/]		0	0	0	0	0	0	0	0	52	56	123	90	149	342	802.5	1,214
Former Shipway/Shoreline Dredge Volume (1,000 cy)		0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Construction Time (years)[4/]		0	1	1	1	1	1	1	1	1	1	1	1	1 to 2	2 to 3	5 to 6	8 to 9
Cost Summary																	
Cost (MM$)[5/]	Capital	0	11.0	12.7	15.8	14.1	14.0	20.3	25.7	27.4	24.8	43.4	33.0	44.5	92.0	203.8	302.8
	ICs, OM&M	0	6.0	6.1	9.2	6.1	8.4	13.7	18.1	5.8	4.1	4.0	4.4	2.4	0.3	0.3	0.0
	Total Cost	0	17.0	18.7	25.0	20.2	22.4	34.1	43.8	33.3	28.9	47.5	37.5	47.0	92.3	204.0	302.8
Performance Summary - RAO 1																	
RAO 1 - Human Seafood Consumption	**COCs**	**Performance Towards Reaching RAO 1 PRGs (%)[6/]**															
	Total PCBs	0	77	85	90	87	83	97	100	90	87	87	88	88	89	92	100
	Arsenic	0	93	100	100	100	99	100	100	100	100	100	100	100	100	100	100
	Copper	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Lead	0	87	94	99	96	92	100	100	97	94	94	93	93	90	100	100
	cPAHs	0	76	80	91	79	86	96	100	89	87	86	76	81	89	88	100
	TBT	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Average	17	89	93	97	94	93	99	100	96	95	94	93	94	95	97	100
Performance Summary - RAO 2, 3, 4		**Risk Threshold Achieved**															
RAO 2 - Human Direct Contact		n/a	$\leq 1x10^{-5}$ [7/]	Cumulative ($\leq 1x10^{-5}$)							Cumulative ($\leq 1x10^{-5}$)				Cumulative ($\leq 1x10^{-5}$)		
RAO 3 - Benthic Organisms		n/a	SQS	SQS							SQS				SQS		
RAO 4 - Ecological		n/a	HQ<1 [8/]	HQ<1							HQ<1				HQ<1		

Notes:

1/ Actively remediated area do not include shipway, shoreline, intertidal habitat remediation area.

2/ Total actively remediated area includes 2 acres for shipway,shoreline, intertidal habitat remediation areas, and site-wide institutional controls.

3/ The performance dredge volume is the neat dredge volume increased by 50%.

4/ One construction year is assumed as 180 days. See Appendix F for estimated number of construction days for each alternative.

5/ See Appendix F for detailed cost estimates.

6/ Based on calculated mean residual site-wide surface sediment concentrations (see Table 12-3).

7/ Alternative 2A1 and 2A4a achieve cumulative direct contact risk of $1x10^{5}$ in sitewide and intertidal areas but PRG for arsenic not achieved (see Table 12-3).

8/ PRG for total PCBs not achieved; average of COC HQ < 1 (see Table 12-3).

cPAH = Carcinogenic Polycyclic Aromatic Hydrocarbon; cy = cubic yard; ENR = Enhanced Natural Recovery; HQ = Hazard Quotient; ICs = Institutional Controls; MM = Millions; OM&M = Operation, Maintenance, Monitoring; n/a = not achieved; PCB = Polychlorinated Biphenyl; RAO = Remedial Action Objective; SQS = Sediment Quality Standard; TBT = Tributyltin.

Table 12-3. Remedial Alternatives, Residual Sitewide Concentrations, and Predicted Outcomes

		Remedial Alternative[1/]															
		1 No Action (Baseline)	2A1 AOPA = SQS Cap CSL and ENR to SQS	2A2a AOPA = Urban Cap CSL and ENR to Urban	2A2b AOPA = Urban Cap SQS and ENR to Urban	2A3 AOPA = Study Area Boundary Cap CSL and ENR to Study	2A4a AOPA = SQS Cap SQS	2A4b AOPA = Urban Cap Urban	2A4c AOPA = Study Area Boundary Cap Study Area Boundary	2B AOPA = Study Area Boundary Remove to Fit 3-ft Cap over CSL, Cap CSL and ENR to Study Area Boundary	3A1 AOPA = Urban Remove upto 3-ft to CSL, Cap to > 2xSQS, ENR to Urban	3A2 AOPA = Urban Remove upto 3-ft to SQS, Cap to > 2xSQS, ENR to Urban	3B AOPA = Urban Remove to CSL in Dry Dock 1, Cap to > 2xSQS, ENR to Urban	3C AOPA = Urban Remove to CSL in Dry Docks, Cap to > 2xSQS, ENR to Urban	4A AOPA = SQS Remove to SQS	4B AOPA = Urban Remove to Urban	4C AOPA = Study Area Boundary Remove to Study Area Boundary
Risk-Driver COCs		**Residual Sitewide Concentration Mean (95% UCL)**															
Total PCBs (ug/kg):		460 (595)	106 (135)	70.3 (153)	46.8 (116)	62.7 (143)	79.3 (104)	14.4 (53.6)	0.1 (0.1)	49 (106)	59.5 (125)	62.5 (129)	55.5 (113)	56.4 (113)	52.5 (77.6)	37.1 (68.7)	2 (2)
Arsenic (mg/kg):		44 (78)	9.5 (18.3)	6.3 (9.8)	4.6 (7.2)	5.8 (9.3)	7.5 (15.2)	2.1 (3.1)	1.4 (1.4)	5.8 (9.3)	6.7 (10.5)	6.7 (9.2)	5.8 (8.7)	6.2 (7.8)	6.8 (8.5)	4 (5.5)	7 (7)
Copper (mg/kg):		270 (489)	51 (73)	38 (42)	33 (37)	36 (47)	46 (67)	27 (29)	25 (25)	30 (35)	35 (47)	34 (39)	38 (54)	35 (51)	35 (57)	17 (19)	25 (25)
Lead (mg/kg):		109 (207)	24 (48)	17 (31)	12 (23)	15 (28)	19 (39)	7.1 (11.1)	4 (4)	14 (25)	17 (30)	17 (32)	17 (32)	18 (23)	21 (27)	10 (12)	11 (11)
Mercury (mg/kg)		0.47 (0.6)	0.156 (0.267)	0.126 (0.194)	0.118 (0.175)	0.11 (0.173)	0.15 (0.248)	0.113 (0.124)	0.1 (0.1)	0.1 (0.203)	0.116 (0.237)	0.115 (0.246)	0.105 (0.201)	0.103 (0.148)	0.095 (0.112)	0.142 (0.592)	0.1 (0.1)
cPAHs (ug/kg):		798 (982)	201 (436)	165 (375)	79.8 (181)	171 (540)	122 (284)	41.7 (124)	9 (9)	98.5 (136)	115 (319)	122 (167)	196 (539)	155 (265)	94.1 (263)	100 (141)	9 (9)
TBT (ug/kg):		700 (2810)	103 (146)	75.1 (228)	42.4 (138)	67.4 (203)	67.6 (94.5)	17.3 (96.9)	0.075 (0.075)	48.7 (143)	60.4 (189)	70.1 (114)	74.1 (218)	69 (106)	78.1 (121)	56.7 (322)	0.075 (0.075)
		Predicted Outcomes for Remedial Action Objectives (RAOs)															
		RAO 1: Human Health – Seafood Consumption [2/]															
	PRGs	**Performance Towards Reaching RAO 1 PRGs from [3/] Mean (%) (95% UCL) (%)**															
Sitewide:																	
Total PCBs:	Nat. Bkd (2 ug/kg)	0 (0)	77 (78)	85 (75)	90 (81)	87 (76)	83 (83)	97 (91)	100 (100)	90 (82)	87 (79)	87 (79)	88 (81)	88 (81)	89 (87)	92 (89)	100 (100)
Arsenic:	Nat. Bkd (7 mg/kg)	0 (0)	93 (84)	100 (96)	100 (100)	100 (97)	99 (88)	100 (100)	100 (100)	100 (97)	100 (95)	100 (97)	100 (98)	100 (99)	100 (98)	100 (100)	100 (100)
Copper:	400	100 (0)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)
Lead:	Nat. Bkd (11 mg/kg)	0 (0)	87 (81)	94 (90)	99 (94)	96 (91)	92 (86)	100 (100)	100 (100)	97 (93)	94 (90)	94 (89)	93 (89)	93 (94)	90 (92)	100 (100)	100 (100)
cPAHs:	Nat. Bkd (9 ug/kg)	0 (0)	76 (56)	80 (62)	91 (82)	79 (45)	86 (72)	96 (88)	100 (100)	89 (87)	87 (68)	86 (84)	76 (46)	81 (74)	89 (74)	88 (86)	100 (100)
TBT:	430 ug/kg	100 (0)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)	100 (100)
		RAO 2: Human Health – Direct Contact [4/]															
Sitewide:																	
Arsenic:	Nat. Bkd (7 mg/kg)	X	X	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
cPAHs:	550 ug/kg	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Intertidal:																	
Arsenic:	Nat. Bkd (7 mg/kg)	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
cPAHs:	150 ug/kg	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		RAO 3: Ecological Health – Benthic[5/]															
Point Basis:	**SMS**	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		RAO 4: Ecological Health – Seafood Consumption															
Sitewide:																	
Total PCBs:	100 ug/kg	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Copper:	114 mg/kg	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TBT:	150 ug/kg	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Intertidal:																	
Copper:	420 mg/kg	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lead:	50 mg/kg	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes:

✓ Meets RAO PRG

X Does not meet RAO PRG

1/ Alternatives 2 through 4 include institutional controls and sitewide monitoring.

2/ For PCBs, cPAHs, arsenic, lead and Dioxins/Furans the PRGs are set to the natural background levels from the Bold Study Survey. Conceptually only an alternative that places a cap over the study area or removes all sediment above the natural background can meet these PRGs. Dioxins/Furans are identified as risk-drivers but because no sediment data for Lockheed West are available, no RBTCs were calculated and no PRGs were developed for the FS. Natural Background is the assumed PRG. Remediation of other risk-driver COCs is expected to address potential risks from dioxins/furans.

3/ Performance towards RAO 1 is to meeting the PRG from the baseline site conditions (i.e., No Action concentrations) based on the calculated mean residual sitewide surface sediment concentrations. Achievement of the PRG results in 100% progress.

$$Progress\ to\ RAO1 = \frac{(Mean\ Baseline\ Concentration - Sitewide\ Average\ Residuals\ Concentration\ )}{(Mean\ Baseline\ Concentration\ - PRG\ Concentration)} x\ 100$$

4/ All alternatives are predicted to achieve the cumulative direct contact risk of 1 x 10-5 in sitewide and in intertidal areas. All alternatives, except 2A1 and 2A4a, have sitewide concentrations for arsenic below the PRG.

5/ Based on calculated mean residual surface sediment concentrations (point basis)

AOPA = Area of Potential Action; ARAR = Applicable or Relevant and Appropriate Requirements; cPAH = Carcinogenic Polycyclic Aromatic Hydrocarbon; CSL = Cleanup Screening Level; ENR = Enhanced Natural Recovery; HQ = Hazard Quotient; MTCA = Model Toxics Control Act; n/a = not applicable; Nat. Bkd. = Natural Background = values are the 95 UCL on the mean data compiled in the "Bold Study" (EPA, 2009a); PCB = Polychlorinated Biphenyl; RAL = Remedial Action Level; RAO = Remedial Action Objective; RBTC = Risk-based Threshold Concentation; SMS = Sediment Management Standards; SQS = Sediment Quality Standard; TBT = Tributyltin; TEQ = Toxic Equivalent; UCL = Upper Confidence Limit on the mean; Urban = Anthropogenic background value is 95 UCL on the mean data reported in Ecology (2008) for the "urban" stations.

Table 12-4. Number of Core Stations Remaining after Construction with SMS Exceedances

			Alternative 1	Alternative 2								Alternative 3				Alternative 4		
			1	2A1	2A2a	2A2b	2A3	2A4a	2A4b	2A4c	2B	3A1	3A2	3B	3C	4A	4B	4C
Number of Cores Remaining after Construction with SMS Exceedances in Actively Remediated Areas [1/, 2/]																		
Actively Remediated Areas	Dredge	>CSL, <3ft		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	1	0	0	0	0	0
		>CSL, >3ft		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	1	0	0	0	0	0
		<CSL, >SQS, <3ft		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1	2	0	0	0	0	0
		<CSL, >SQS, >3ft		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	2	0	0	0	0	0
	Cap	>CSL, <3ft		18	18	20	18	20	20	20	18	5	5	7	1	n/a	n/a	n/a
		>CSL, >3ft	n/a	9	9	11	9	11	11	11	9	3	3	2	0	n/a	n/a	n/a
		<CSL, >SQS, <3ft		1	1	4	1	4	6	8	1	1	1	1	2	n/a	n/a	n/a
		<CSL, >SQS, >3ft		2	2	2	2	2	3	5	2	1	1	2	0	n/a	n/a	n/a
	ENR	>CSL, <3ft		2	2	0	2	0	0	0	2	3	0	4	4	0	0	0
		>CSL, >3ft		2	2	0	2	0	0	0	2	3	0	3	3	0	0	0
		<CSL, >SQS, <3ft		3	5	2	7	0	0	0	7	4	3	5	5	0	0	0
		<CSL, >SQS, >3ft		0	1	1	3	0	0	0	3	1	1	1	1	0	0	0
Baseline	No Action	>CSL, <3ft	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		>CSL, >3ft	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		<CSL, >SQS, <3ft	8	4	2	2	0	4	2	0	0	2	2	2	2	4	2	0
		<CSL, >SQS, >3ft	5	3	2	2	0	3	2	0	0	2	2	2	2	3	2	0

Notes:

1/ > CSL - at least one parameter was above the CSL in one sample interval for the depth. Cores organized as <3ft and >3ft. <CSL, >SQS - at least one parameter is above the SQS and no parameters are above the CSL in one sample interval for the depth.

2/ Data from 51 sediment cores of greater than 1 foot were used in the SMS exceedance evaluation. Thirteen of the cores had no SMS exceedances detected at all and ten did not have a SMS exceedance at a depth greater than 1 foot below the mudline surface. Therefore, the evaluations are based on 28 cores.

CSL = Cleanup Screening Level; ENR = Enhanced Natural Recovery; n/a = not applicable; SQS = Sediment Quality Standard.

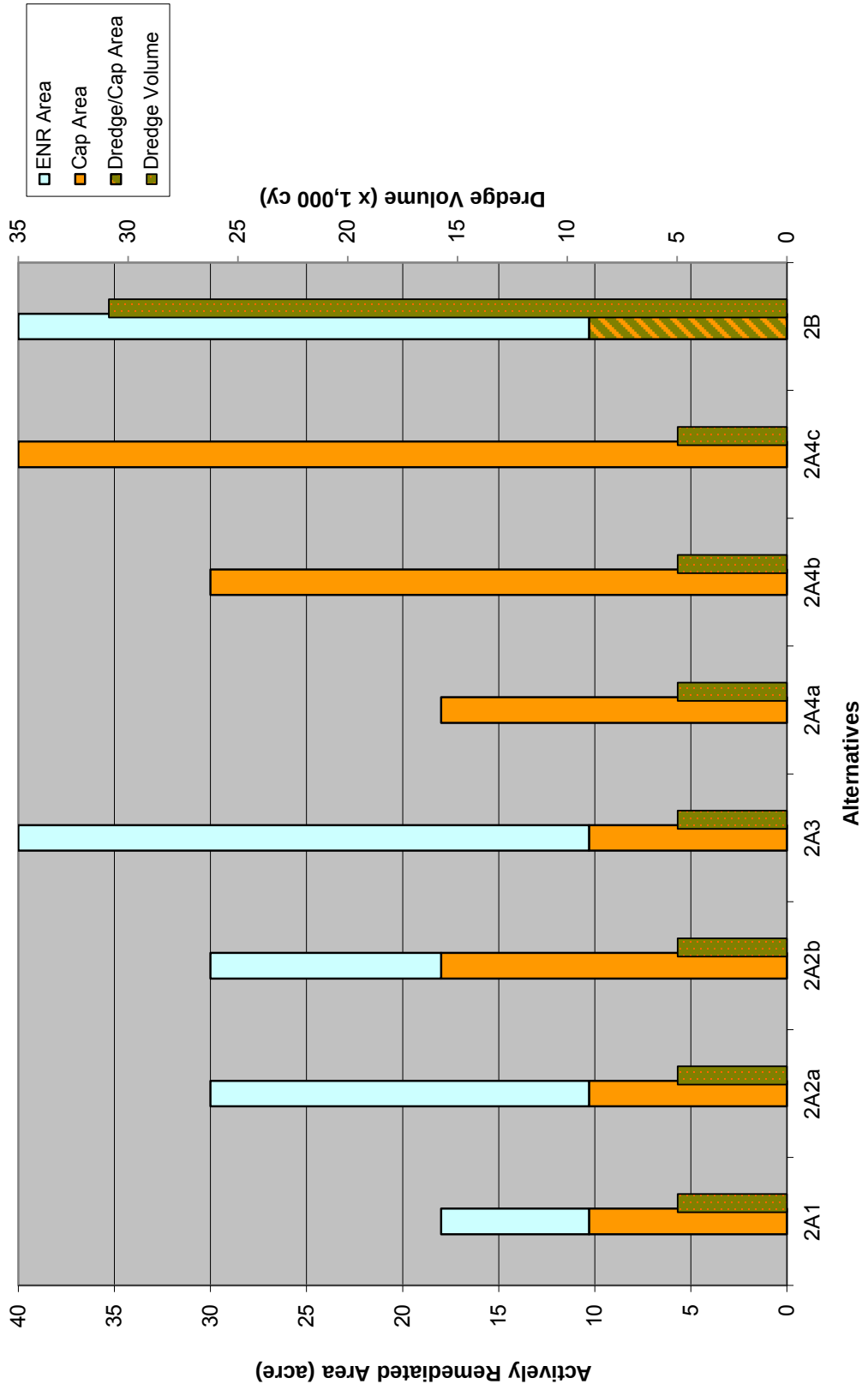

Figure 12- 1. Alternative 2 - Actively Remediated Area and Dredge

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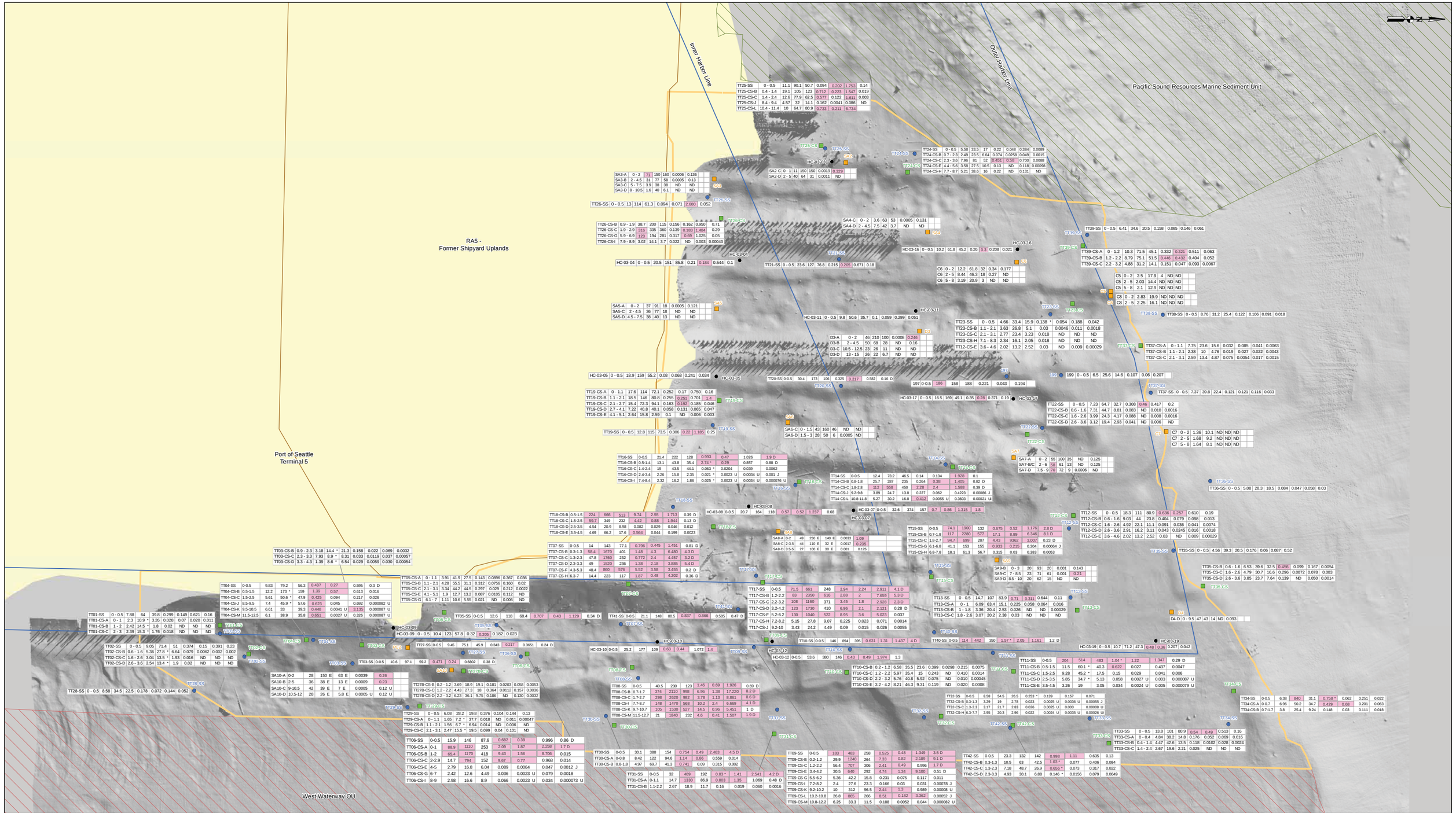

TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure 12-2
Residual Risk-Driver Contaminant Concentrations (Pre-ENR/Cap Placement) Capping and ENR Alternatives

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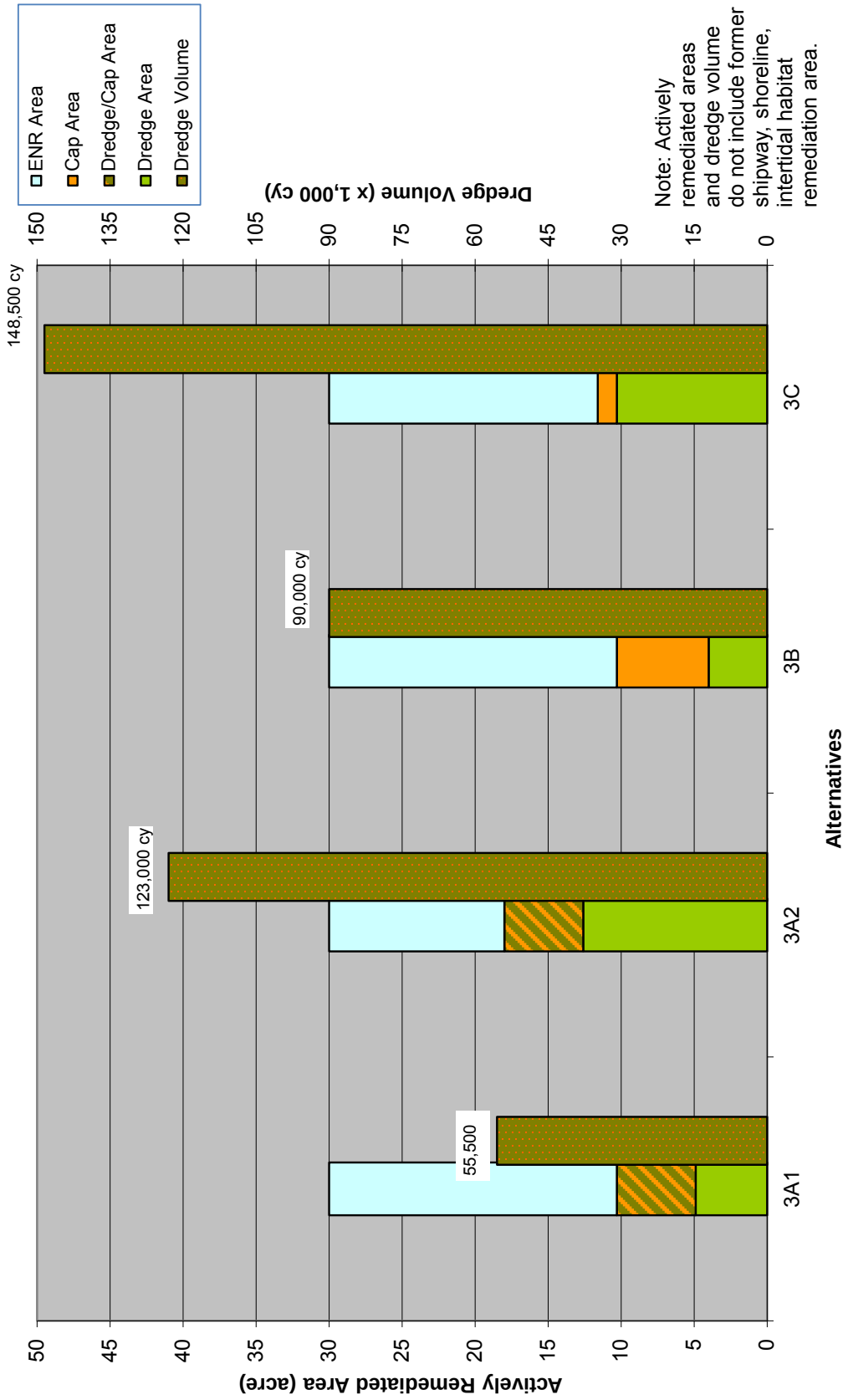
Figure 12-3. Alternative 3 - Actively Remediated Area to Dredge Volume



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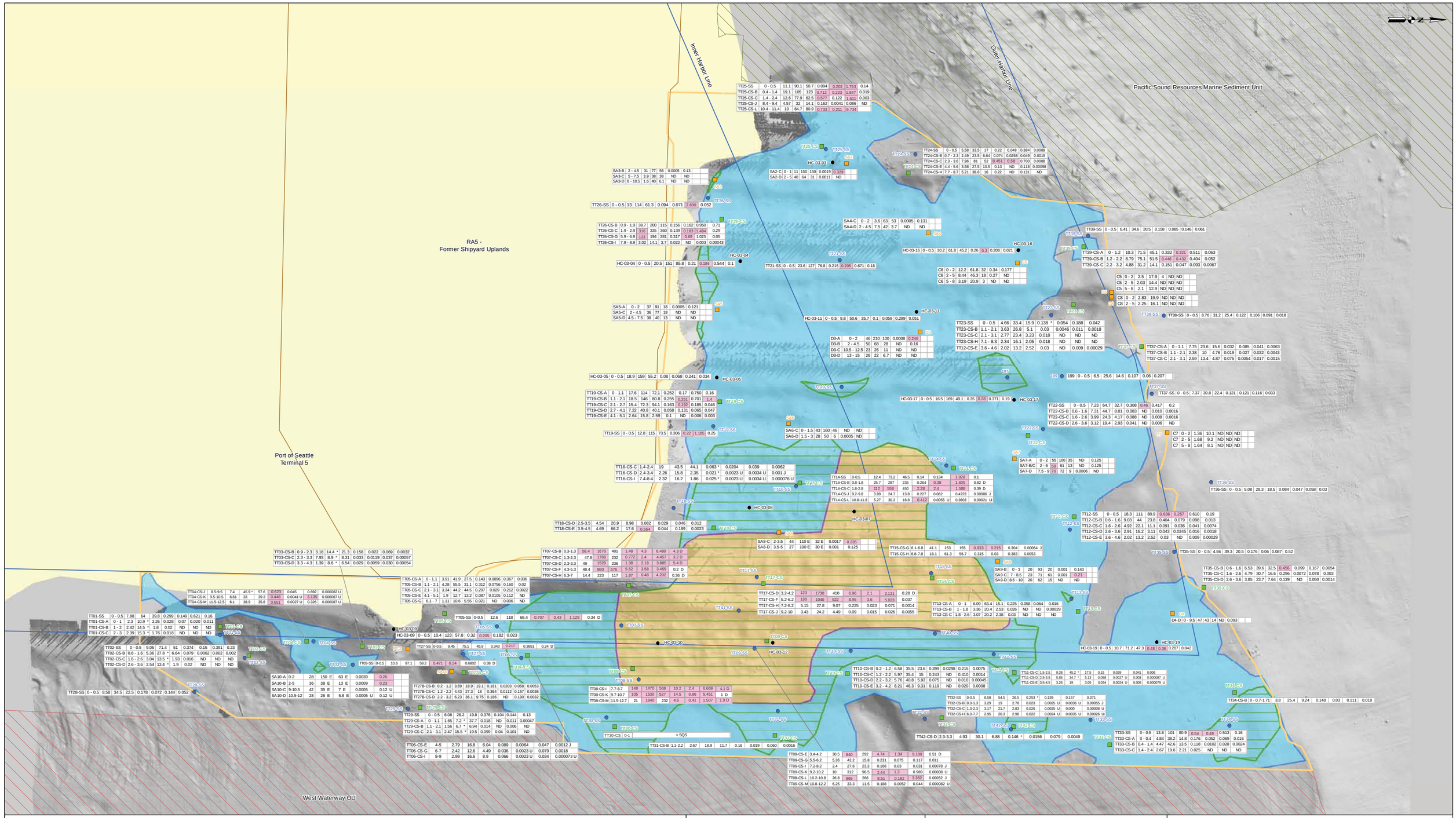

Legend

1998 and Earlier Sampling Locations

- Subsurface Core Sample Location

2003 Sampling Locations

- Surface Grab Sample Location

2007 Sampling Locations

- 2007 RI Subsurface Core Sample Location
- 2007 RI Surface Grab Sample Location

- Lockheed West Study Area
- Harbor Lines
- Pacific Sound Resources Marine Sediment Unit (approximate)
- West Waterway OU (approximate)
- RA5 - Former Shipyard Uplands
- Remove to CSL Footprint
- Cap to 2XSQS
- ENR to Urban

Sample ID	Depth Interval Below Post Remedy Mudline	As	Cu	Pb	Hg	PCB	cPAH	TBT
SA5-B	0 - 2 ft							

Colored Box Indicates Result > SQS

Notes:
AC = Acre
AOPA = Area of Potential Action
CSL = Cleanup Screening Level
CY = Cubic Yard
ENR = Enhanced Natural Recovery

Feet
0 50 100 200

TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure 12-4
Residual Risk-Driver Contaminant Concentrations (Pre-ENR/Cap Placement) Alternative 3A1

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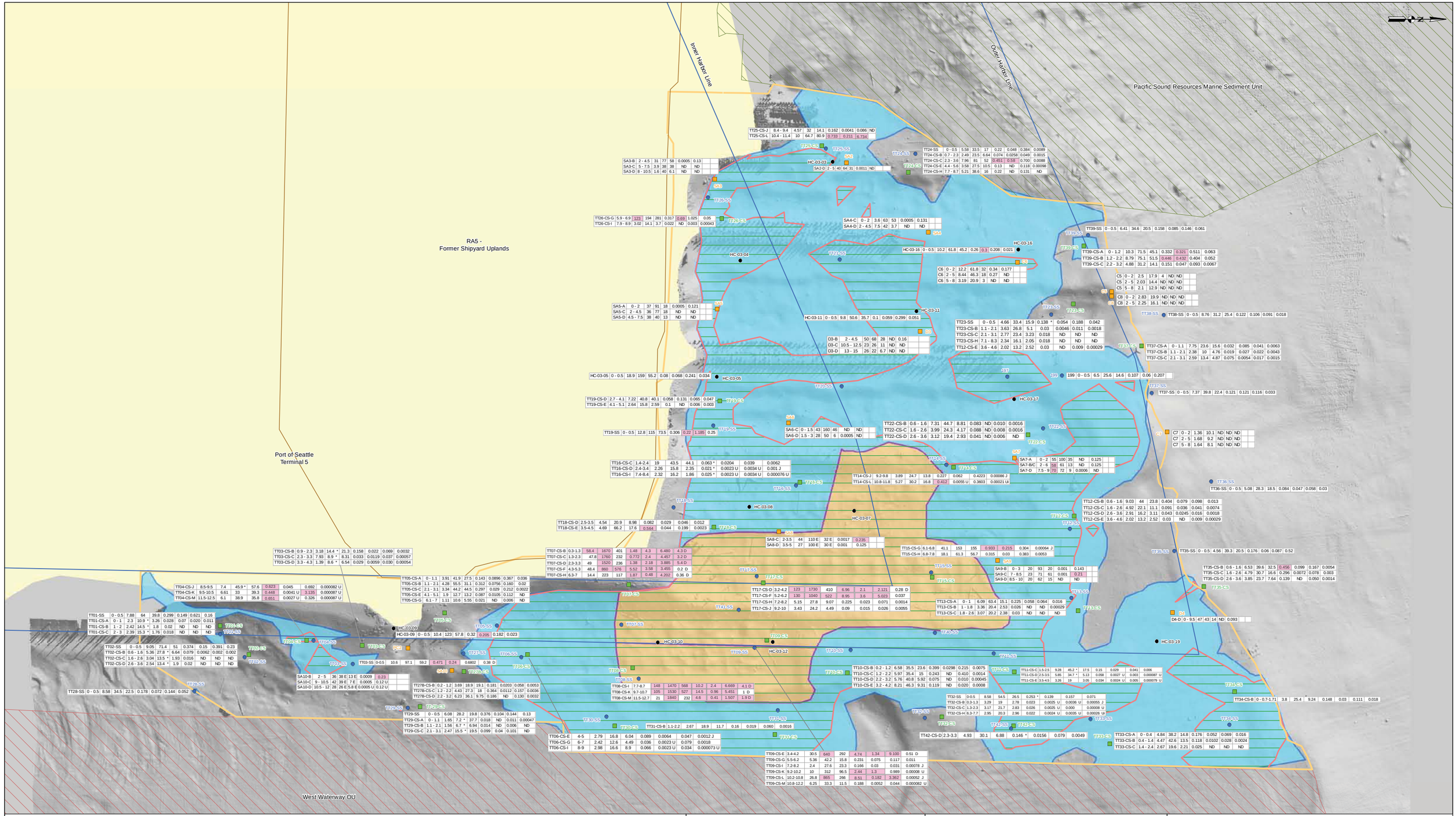

Legend

1998 and Earlier Sampling Locations

- Subsurface Core Sample Location

2003 Sampling Locations

- Surface Grab Sample Location

2007 Sampling Locations

- 2007 RI Subsurface Core Sample Location
- 2007 RI Surface Grab Sample Location

- Lockheed West Study Area
- Harbor Lines
- Pacific Sound Resources Marine Sediment Unit (approximate)
- West Waterway OU (approximate)
- RA5 - Former Shipyard Uplands
- Remove to SQS Footprint
- Cap to 2XSQS
- ENR to Urban

Sample ID	Depth Interval Below Mudline (Post Remedy)	As	Cu	Pb	Hg	PCB	cPAH	TBT
SA5-B	0 - 2 ft							

Colored Box Indicates Result > SQS

Notes:
AC = Acre
AOPA = Area of Potential Action
CSL = Cleanup Screening Level
CY = Cubic Yard
ENR = Enhanced Natural Recovery

0 50 100 200 Feet

TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure 12-5
Residual Risk-Driver Contaminant Concentrations (Pre-ENR/Cap Placement) Alternative 3A2

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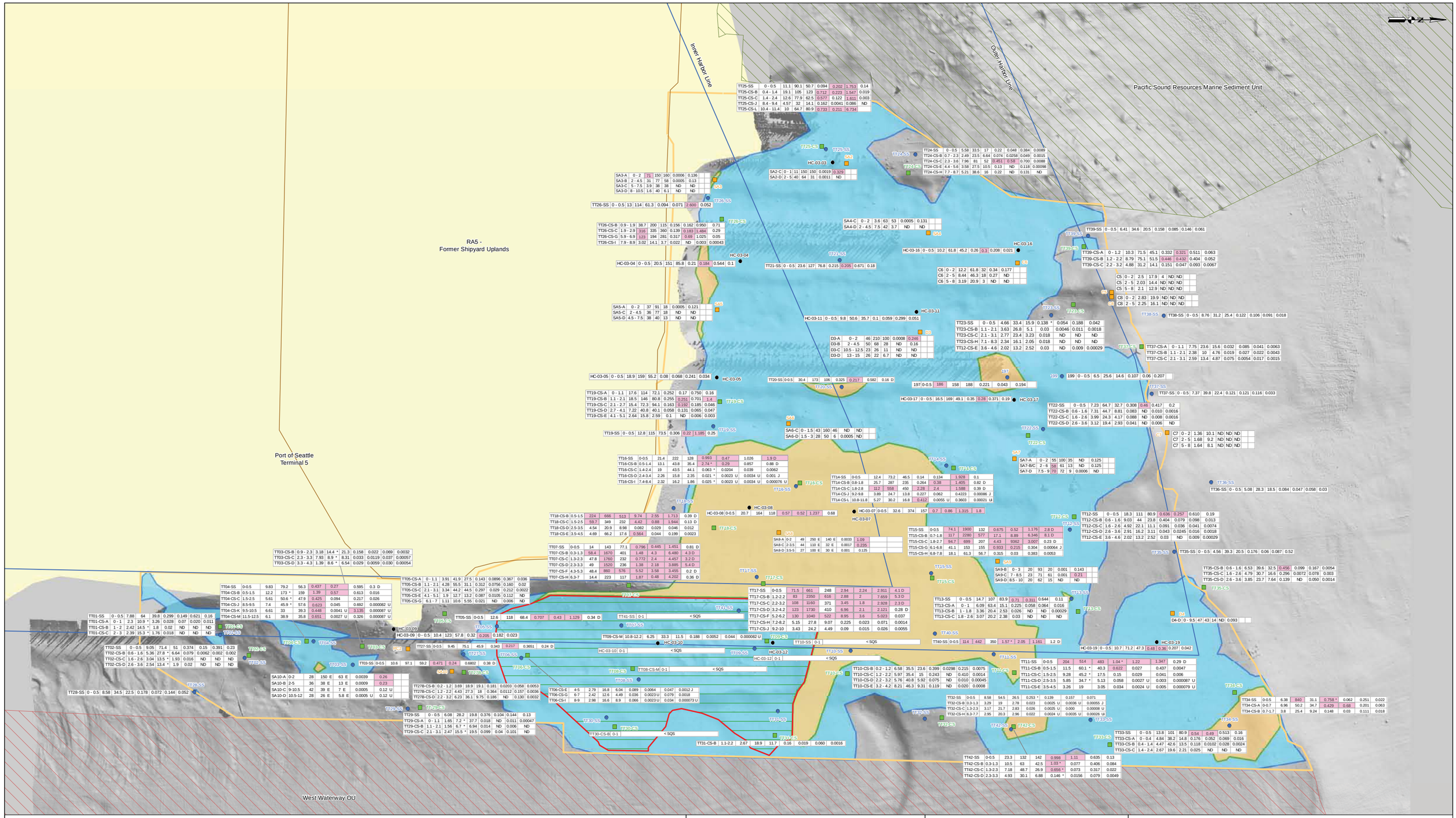

Legend

1998 and Earlier Sampling Locations

- Subsurface Core Sample Location

2003 Sampling Locations

- Surface Grab Sample Location

2007 Sampling Locations

- 2007 RI Subsurface Core Sample Location
- 2007 RI Surface Grab Sample Location

- Lockheed West Study Area
- Harbor Lines
- Pacific Sound Resources Marine Sediment Unit (approximate)
- West Waterway OU (approximate)
- RA5 - Former Shipyard Uplands
- Remove to CSL in Dry Dock 1
- Cap to CSL
- ENR to Urban
- Cap to CSL

Sample ID	Depth Interval Below Post Remedy Mudline	As	Cu	Pb	Hg	PCB	cPAH	TBT
SA5-B	0 - 2 ft							

Colored Box Indicates Result > SQS

Notes:
AC = Acre
AOPA = Area of Potential Action
CSL = Cleanup Screening Level
CY = Cubic Yard
ENR = Enhanced Natural Recovery

Feet
0 50 100 200

TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure 12-6
Residual Risk-Driver Contaminant Concentrations (Pre-ENR/Cap Placement) Alternative 3B

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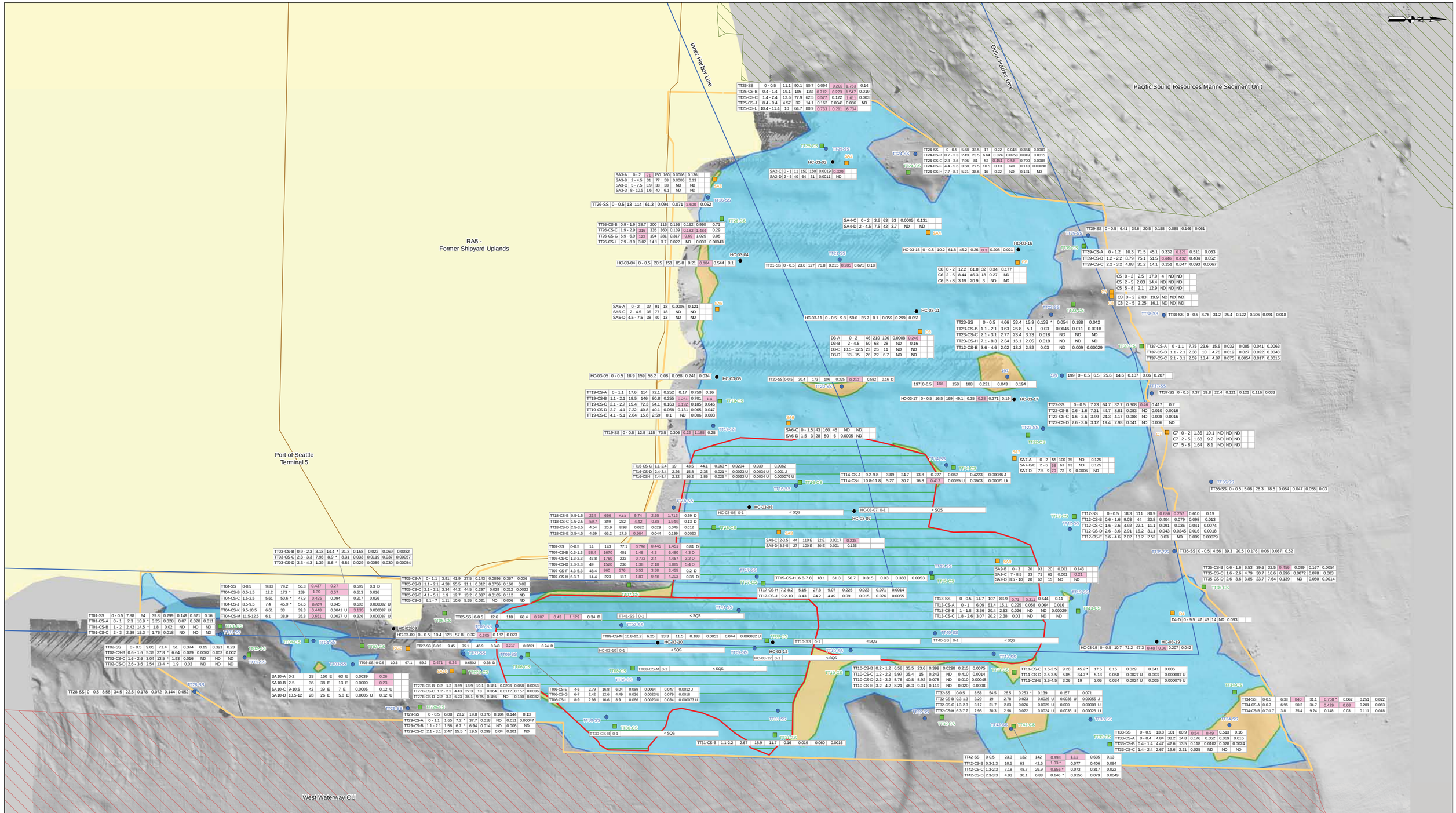

Legend

1998 and Earlier Sampling Locations

- Subsurface Core Sample Location

2003 Sampling Locations

- Surface Grab Sample Location

2007 Sampling Locations

- 2007 RI Subsurface Core Sample Location
- 2007 RI Surface Grab Sample Location

- Lockheed West Study Area
- Harbor Lines
- Pacific Sound Resources Marine Sediment Unit (approximate)
- West Waterway OU (approximate)
- RA5 - Former Shipyard Uplands
- Remove to CSL in Dry Dock Areas
- Cap to CSL
- ENR to Urban
- Former Dry Dock Areas

Sample ID	Depth Interval Below Mudline	As	Cu	Pb	Hg	PCB	cPAH	TBT
SA5-B	0 - 2 ft					▲		

Colored Box Indicates Result > SQS

Notes:
AC = Acre
AOPA = Area of Potential Action
CSL = Cleanup Screening Level
CY = Cubic Yard
ENR = Enhanced Natural Recovery

Feet
0 50 100 200

TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure 12-7
Residual Risk-Driver Contaminant Concentrations (Pre-ENR/Cap Placement) Alternative 3C

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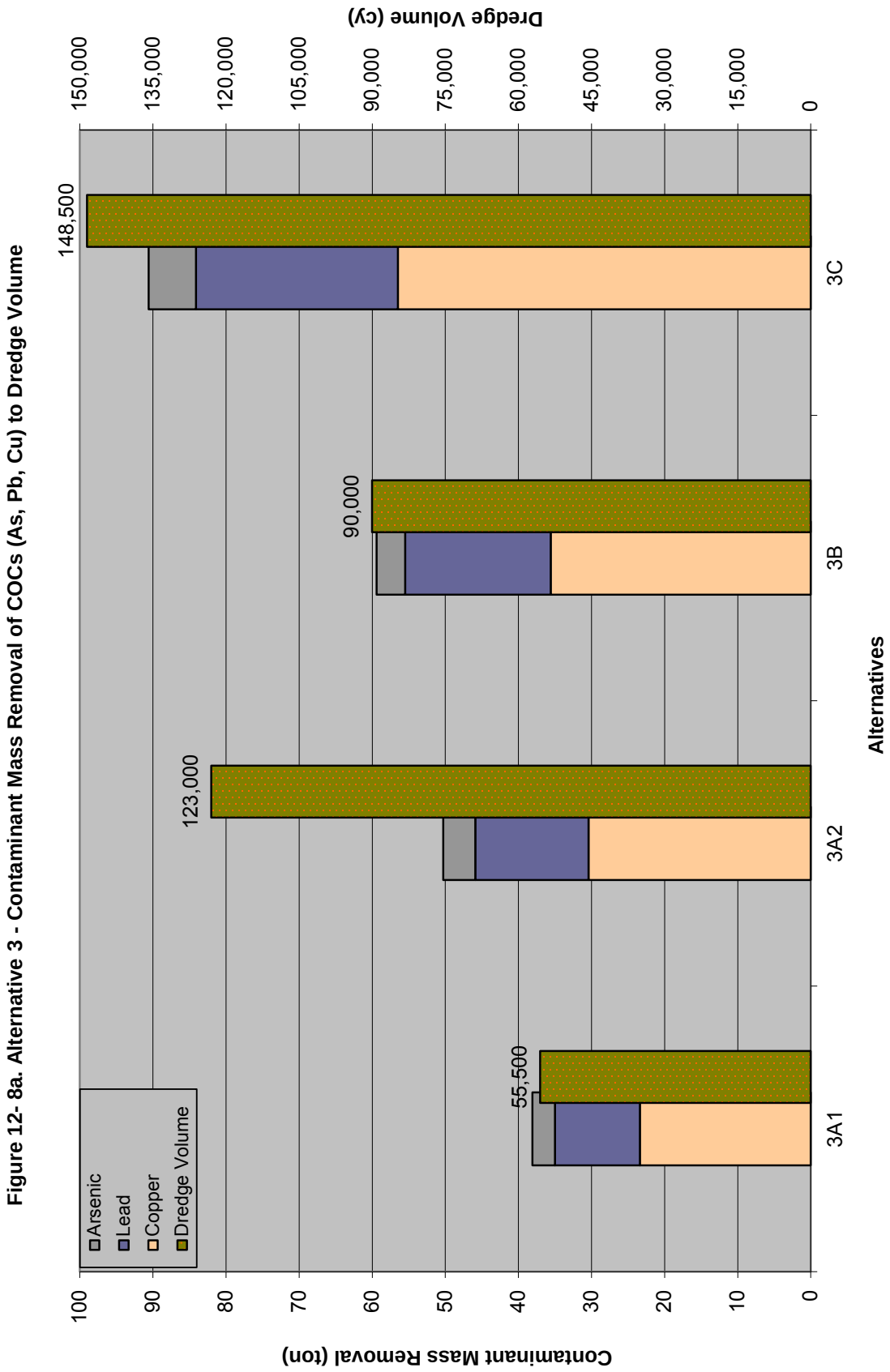


Figure 12- 8a. Alternative 3 - Contaminant Mass Removal of COCs (As, Pb, Cu) to Dredge Volume
Arsenic
Lead
Copper
Dredge Volume
Contaminant Mass Removal (ton)
Dredge Volume (cy)
100
90
80
70
60
50
40
30
20
10
0
150,000
135,000
120,000
105,000
90,000
75,000
60,000
45,000
30,000
15,000
0
55,500
123,000
90,000
148,500
3A1
3A2
3B
3C
Alternatives

Figure 12- 8b. Alternative 3 - Contaminant Mass Removal of COCs (Hg, PCBs, cPAHs, TBT) to Dredge Volume

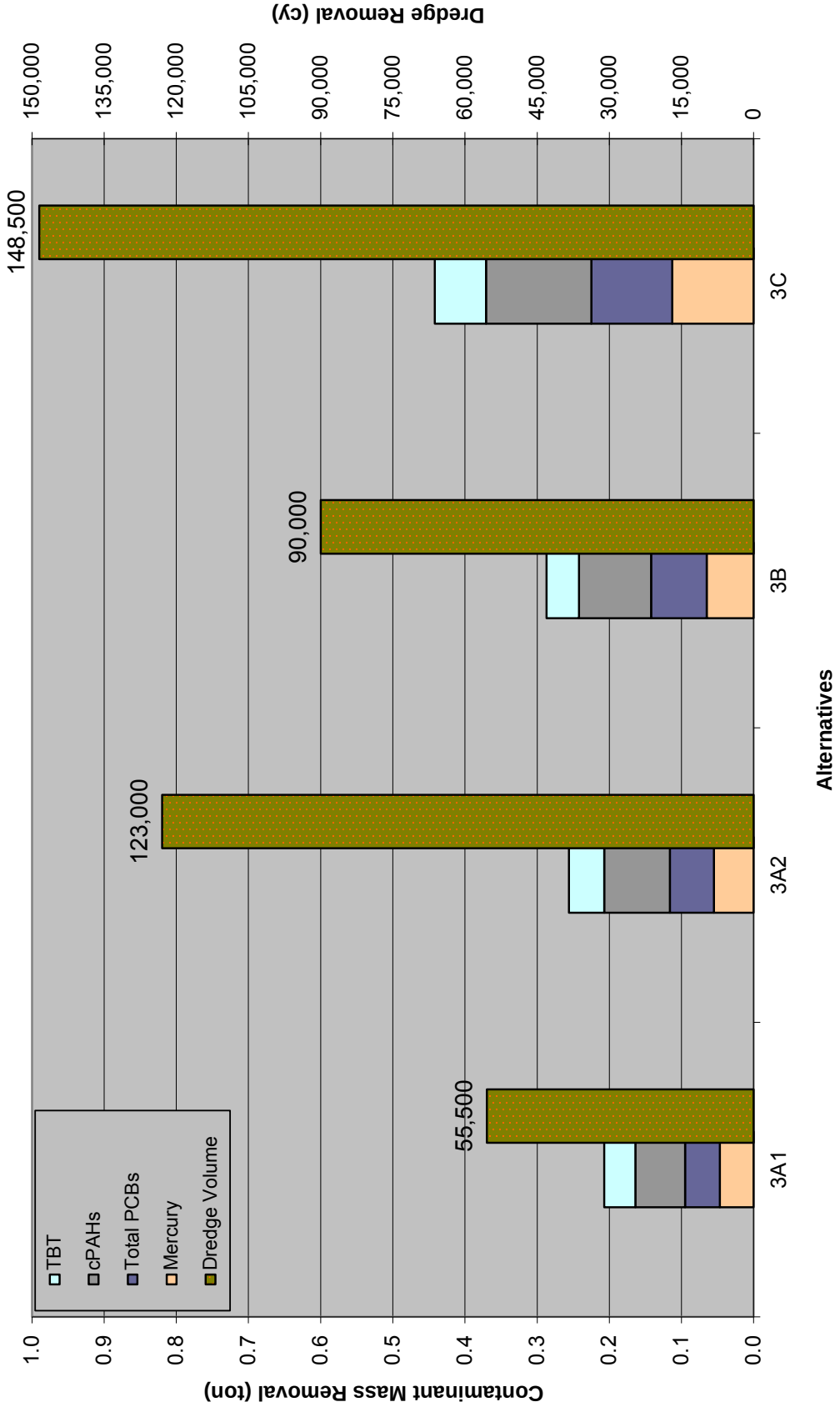
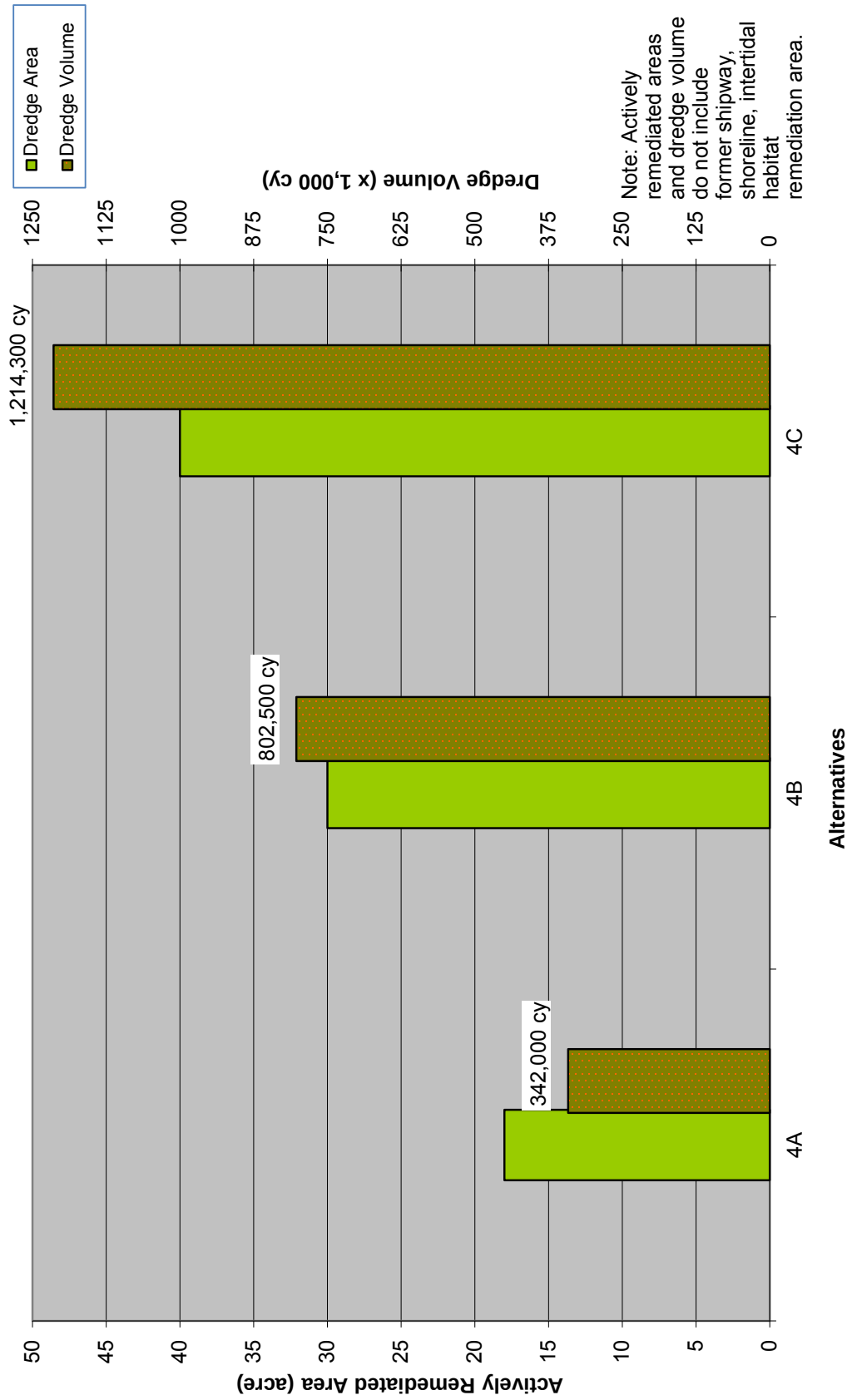


Figure 12-9. Alternative 4 - Actively Remediated Area to Dredge Volume



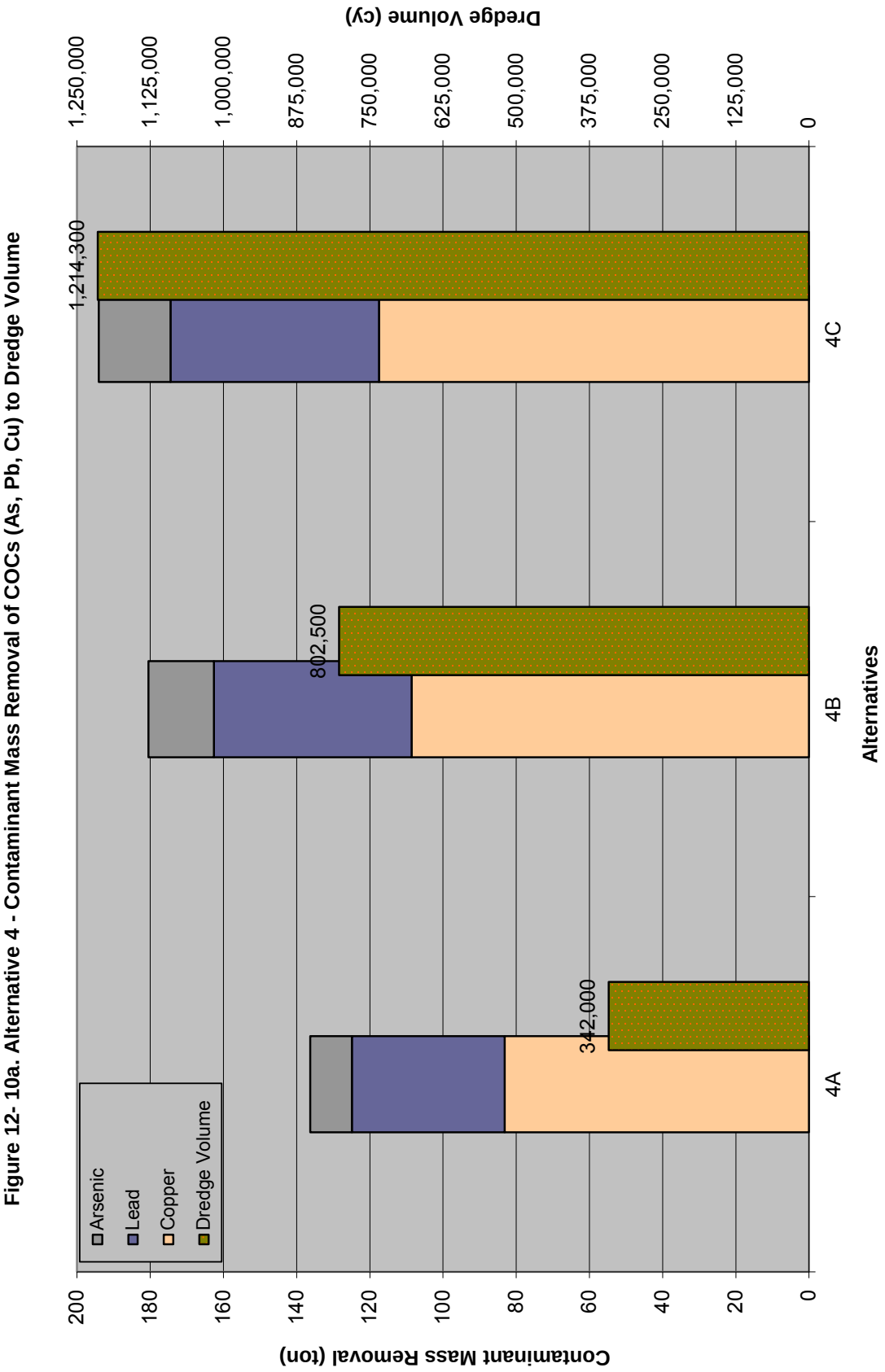
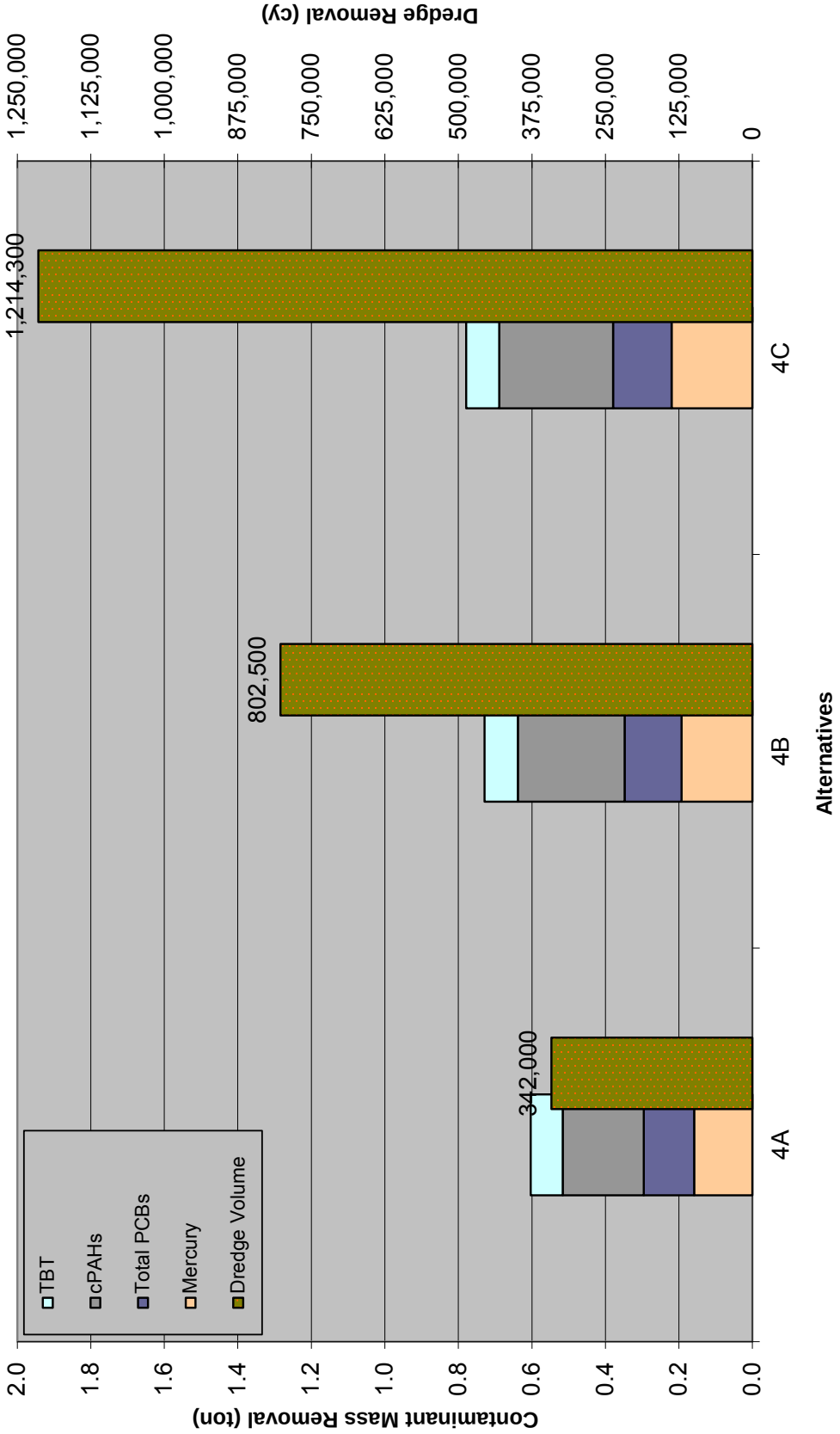


Figure 12- 10a. Alternative 4 - Contaminant Mass Removal of COCs (As, Pb, Cu) to Dredge Volume

Figure 12- 10b. Alternative 4 - Contaminant Mass Removal of COCs (Hg, PCBs, cPAHs, TBT) to Dredge Volume



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SECTION 13
Comparative Analysis of Remedial Alternatives

This section provides a comparative evaluation of the Lockheed West Site remedial alternatives developed in Section 11 and evaluated individually in Section 12 to assess the relative performance of each alternative with respect to each evaluation criterion (e.g., threshold, balancing, and modifying criteria) under CERCLA and to identify the key tradeoffs between them.

In this FS, the remedial alternatives and subalternatives were developed using a range of AOPAs (i.e., the areas of the site where the risk-driver sediment chemical concentrations are elevated relative to a set of threshold concentrations) and potential RALs to assign the extent and scale of active cleanup for each alternative. The alternatives were assembled as the No Action alternative (Alternative 1), containment-focus alternatives (Alternatives 2A1, 2A2a, 2A2a Plus, 2A2b, 2A3, 2A4a, 2A4b, 2A4c, and 2B), removal-focus alternatives (Alternatives 3A1, 3A2, 3A2 Plus, 3B, 3C, and 3C Plus), and complete removal alternatives (Alternatives 4A, 4B, and 4C). Figure 13-1 illustrates the active remediation areas and removal volumes for the alternatives with dredging components except for the FS Alternative variations (Appendix I).

Late in the review process and following EPA comments on the draft RI/FS document, EPA requested consideration of several variations to the alternatives in this section (see Appendix I). Alternatives 2A2a, 3A2, and 3C serve as base alternatives for the FS alternative variations 2A2a Plus, 3A2 Plus, and 3C Plus. Focused comparative analyses of these FS alternative variations relative to the outcome of the analysis in this section, found in Section 13.5, are provided in Appendix I.

13.1 METHODOLOGY FOR COMPARATIVE ANALYSIS AND RANKINGS

The alternatives are first evaluated for whether they meet or do not meet threshold criteria (i.e., overall protection of human health and the environment and compliance with ARARs), which serve as threshold determinations in that they must be met by any alternative for it to be eligible for selection. Balancing criteria (i.e., long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost) are then considered, and generally require more discussion because the major tradeoffs among alternatives are typically related to these criteria (EPA, 1988).

The evaluation of alternatives performed in Chapter 12 is summarized across all alternatives in Table 13-1. The first several rows of Table 13-1 summarize the performance of the remedial alternatives in achieving the threshold criteria. The rest of the table presents the summary of Chapter 12 discussions for the balancing criteria.

A comparative rankings analysis was performed to evaluate the relative overall ranking of each remedial alternative. This relative ranking was used to more thoroughly distinguish similarities and dissimilarities among the alternatives. The methodology for the comparative analysis rankings is generally explained below and the metrics compiled in Table 13-2. Similar comparative analysis ranking techniques have been utilized to support decision-making regarding the selection of the preferred remedial alternative for several Superfund sites in the Pacific Northwest (e.g., Pacific Sound Resources, Port of Portland Terminal 4, and Lower Duwamish Waterway).

Metrics were developed for the scoring criteria in Table 13-2 based on a zero to 10 rating scale. The rating scale is a linear relationship, with a minimum performance given a rating of zero and the maximum performance with full achievement given a rating of 10. The bases for each of the metrics used to develop the scores in Table 13-2 are described under the evaluation of each criterion in the following sections.

Each of the CERCLA evaluation criteria are represented by one or more individual metrics. When a criterion has multiple metrics, the individual metric scores were averaged to give an overall scoring for the criteria. For example, four individual metrics were developed to assess the overall protection of human health and the environment criterion (i.e., basis of how alternatives

meet PRGs associated with RAOs), and those four scores were averaged to provide an overall average score for this criterion.

After calculating an average for each criterion, an overall score was calculated to use for the overall comparison. The overall score was calculated on a weighted and unweighted basis. The unweighted basis is simply the average of the overall evaluation criteria ratings. The weighted basis applies weightings to each CERCLA evaluation criteria. Overall protection of human health and the environment and compliance with ARARs are threshold criteria and all alternatives equally comply at the end of construction; these criteria were not included in the weighted or average score calculations. For the primary balancing criteria, a weighting of 50 was given to long-term effectiveness and permanence because it is an important criterion for how the remedial actions reduce risk, what controls are required, and whether those controls are adequate to maintain protection from future exposures to contamination. Short-term effectiveness and implementability were each assigned weighting factors of 25. Thus, the overall sum of weighting factors for the primary balancing criteria is 100.

The resulting overall scores are evaluated against the cost of the alternatives. Modifying criteria (i.e., state and community acceptance) are not taken into account in this analysis because these criteria will be addressed by EPA in the development of the Proposed Plan and ROD.

In the following sections, comparative evaluation of the alternatives is performed based on the detailed evaluation presented in Section 12 and information compiled in Tables 13-1 and 13-2.

13.2 THRESHOLD CRITERIA

The EPA (1988) guidance and the NCP (40 CFR 300.430[e][9][iii]) require evaluation of alternatives for their ability to satisfy two threshold criteria: 1) overall protection of human health and the environment and 2) compliance with ARARs.

13.2.1 Overall Protection of Human Health and the Environment

Alternative 1, the No Action alternative, takes no measures to protect human health and the environment. Other alternatives meet the threshold criterion for overall protection of human health and the environment by achieving the four RAOs by implementation of the engineered

remedy and application of appropriate institutional controls, and providing monitoring to ensure the PRGs associated with the RAOs are achieved.

All active alternatives except Alternative 4C require institutional controls. In particular, seafood consumption advisories, public education, and outreach are needed to reduce human exposures to resident seafood, because all the alternatives except Alternatives 2A4c and 4C are not capable of lowering risk-driver COCs to their respective PRGs, which are set at natural background. Alternatives 2A4c (conventional capping to the study area boundary) and 4C (removal to the study area boundary) would achieve RAO 1 PRGs at the completion of construction and therefore would not require a specific seafood consumption advisory; however, the existing regional consumption advisories would still apply. The reason for this is there will be restrictions on the number of fish that can be consumed even if the cleanup meets the PRGs because they (natural background levels in most cases) are higher than the RBTCs. Alternative 2A4c would require institutional controls (i.e., notification of waterway users and future use restrictions) to protect conventional capping that would be constructed to the study area boundary. Other alternatives would provide incremental risk reduction and average 89 percent to 99 percent progress towards reaching RAO 1 PRGs from the mean baseline conditions using the methodology explained in Section 12.1.2, and thus would require institutional controls to reduce human exposures to resident seafood (Table 13-1). At the end of construction and in the short term, the remediated areas will result in a clean surface. In the long term, with sediment mixing (as described for ENR) and new sediment deposition at the Site, the surface sediment concentrations are likely to increase, especially for PCBs and cPAHs where the sediment concentrations in Elliott Bay are above the natural background concentrations. Comparative scoring of the alternatives for the protection of human health and environment based on the achievement of the RAO 1 PRGs due to implementation of the remedy and excluding application of institutional controls is presented in Table 13-2. For RAO 1, a 100 percent achievement rating was given a score of 10 and no progress from the baseline conditions (i.e., Alternative 1) was given a score of zero.

The scores for RAO 1 range from 8.9 (Alternative 2A1) to 10 (Alternatives 2A4c and 4C). A general summary of all remedial alternatives showing the progress toward reaching RAO 1 PRGs without institutional controls is illustrated in Figure 13-2. For RAOs 2 through 4, the

achievement of the PRGs associated with the RAO was rated 10 and the non-achievement was rated zero, with Alternatives 2A1 and 2A4a receiving a rating between zero and 10 for achieving some but not all of the PRGs immediately at completion of construction.

Major differences in overall protectiveness of Alternatives 2, 3, and 4 are largely in the long-term effectiveness and permanence and short-term effectiveness criteria. In the long term, removal-focus and complete removal alternatives would pose a low to very low potential of re-exposure from the subsurface contamination that remains in place. The containment-focus alternatives with smaller AOPA footprints would leave slightly more subsurface contamination that could potentially be re-exposed by physical disturbance mechanisms. This potential is gauged as low to moderate, with the assumption that portions of the Site designated for cap and ENR would be monitored in the long-term and corrective measures (e.g., repair of cap and ENR cover) would be implemented if necessary. Furthermore, reliance on institutional controls is expected where subsurface contamination remains above protective levels to reduce the potential for re-exposure. The risk for re-exposing remaining subsurface contamination due to seismic events is considered moderate for Alternative 2, low to moderate for Alternatives 3 and 4A, and low for Alternatives 4B and 4C. The risk and potential hazard from a seismic slope stability failure or a larger scale flow slide is the same for all alternatives.

Re-exposure of subsurface contamination is primarily a matter of concern in the context of meeting PRGs associated with RAO 3, which has a point-based compliance standard and is therefore more influenced by localized re-exposures. Re-exposure is less of a concern for maintaining PRGs associated with RAOs 1, 2, and 4, because the PRGs for these are all based on sitewide average concentrations and are therefore less subject to influence by localized or small-scale re-exposures.

In the context of short-term effectiveness, the containment-focus alternatives can be implemented more quickly than the removal-focus alternatives for the same AOPAs. Shorter construction periods would have lower impacts to workers, the community, and the environment during implementation. Conversely, longer construction periods result in higher short-term impacts. Alternatives 2 and 3 would be implemented in one construction season with the exception of Alternative 3C, which may require two construction seasons to complete its in-

water remedial activities. Alternatives 4A, 4B, and 4C have construction periods ranging from 3 to 9 years and would result in greater short-term impacts than the other alternatives.

In summary, Alternatives 2, 3, and 4 achieve the threshold criterion of overall protection of human health and the environment, achieving RAO 1 through implementation of the engineered remedy and institutional controls, and achieving PRGs associated with RAO 2, 3, and 4 through implementation of the engineered remedy. Alternatives 2, 3, and 4 (except Alternatives 2A1 and 2A4a) scored higher than 9.8 without considering the application of institutional controls (Table 13-2). Alternative 1 does not achieve this threshold criterion.

13.2.2 Compliance with Applicable or Relevant and Appropriate Requirements

The remedial alternatives were developed and evaluated against their compliance to the three most important ARARs: SMS (WAC 173-204); Surface Water Quality Standards (Revised Code of Washington 90-48; WAC 173-201A); and the state MTCA (WAC 173-340-700[5][d]). Section 9 of this report introduced other chemical-specific, location-specific, and action-specific ARARs that were not discussed explicitly as part of the detailed evaluation of remedial alternatives in Section 12. These other ARARs are largely procedural and influence how materials are handled and disposed of. Table 9-1 lists all ARARs and project-specific comments for each ARAR. Other than the three key ones, the ARARs mostly cover management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste) and may affect implementation, but they do not have a significant effect on whether a remedial alternative is fundamentally viable. Refer to Sections 12.1.1.2 and 13.2.2.4 for additional discussion and compliance with other ARARs. As described below, broad compliance with ARARs is considered to be feasible for the remedial alternatives at the FS level of analysis. The remedial alternatives (with the exception of Alternative 1) can be designed to ensure compliance with ARARs through required engineering design and agency review.

13.2.2.1 Compliance with SMS

Cleanup standards under the SMS are established by Ecology on a location-specific basis within an allowable range of concentrations. The upper end of this range is the minimum cleanup level that must be met within 10 years of completion of the active cleanup actions; this level represents the CSL (i.e., the upper end of minor adverse effects for benthic organisms). The lower end is the

cleanup objective and is equivalent to the SQS. Site-specific cleanup standards are to be as close as practicable to the cleanup objective. Factors considered for identification of site-specific sediment cleanup standards include environmental effects, technical feasibility, and cost.

Alternative 1 is not expected to comply with the SMS. Alternatives 2, 3, and 4 are considered compliant with the SMS. As noted in Section 9, RAO 3 (ecological health – benthic) identifies the SQS as the PRG for the Lockheed West Site sediments. All alternatives are in compliance with SMS at the end of the remedial construction (Table 13-1) and given the highest score of 10 for meeting RAO 3 (Table 13-2). Cleanup standards will be established in the final decision documents consistent with the SMS.

13.2.2.2 Compliance with Surface Water Quality Standards

Compliance with surface water quality ARARs is both a short-term and long-term requirement. All of the remedial alternatives must comply with Surface Water Quality Standards (WAC 173-201A) during construction. Regardless of the remedial alternative selected, the project would comply with the project-specific water-quality certification requirements, provided that dredging and capping methods include best management practices to ensure that dissolved and/or suspended releases of total suspended solids and dissolved COCs do not result in exceedances of water quality standards (EPA, 2005b; NRC, 2007).

RAO 1 (human health seafood consumption) includes compliance with water quality standards for protection of human health (i.e., risk-based standards based on the seafood consumption pathway under WAC 173-201A). Cleanup of sediments is expected to reduce COCs in the water column following cleanup actions. Other factors not related to releases from the Site also contribute to chemical concentrations in water (Tetra Tech, 2009a,b). Monitoring will assess whether this ARAR can be attained in the long term or whether a waiver would be required.

13.2.2.3 Compliance with Model Toxics Control Act

The state MTCA regulations governing the selection of cleanup standards are ARARs under CERCLA. These regulations provide that sediment cleanup levels cannot be set at concentrations lower than natural background when RBTCs (based on 1×10^{-6} excess cancer risk threshold) are below natural background (WAC 173-340-705[6]). For the Lockheed West Site, this applies to

total PCBs, arsenic, lead, and cPAHs for the human seafood consumption scenario and arsenic for all direct contact scenarios.

For RAO 2 (human health direct contact), all alternatives meet MTCA requirements for cumulative excess cancer risks (at or below 1×10^{-5}) at completion of construction. Alternatives 2A1 and 2A4a do not meet the PRG for arsenic (which is based on natural background concentrations). This is reflected in the relative benefits scoring evaluation presented in Table 13-2. All of the alternatives except 4C leave contaminated sediment on-site above the estimated natural background cleanup levels for total PCBs and cPAHs. Alternative 2A4c achieves the natural background concentrations through placement of a conventional cap to the study area boundary. The other alternatives comply with the MTCA ARARs by a combination of reducing concentrations (i.e., average 89 percent to 100 percent from the mean baseline conditions) and using institutional controls designed to reduce human consumption of resident fish and shellfish (WAC 173-340-360 and -370). At the end of construction and in the short term, the remediated areas will result in a clean surface. In the long term, with sediment mixing (as described for ENR) and new sediment deposition at the Site, the surface sediment concentrations are likely to increase, especially for PCBs and cPAHs where the sediment concentrations in Elliott Bay are above the natural background concentrations.

13.2.2.4 Compliance with other ARARs

The construction elements for the remedial alternatives developed for the Lockheed West Site sediments are similar in nature and scope to ARAR-compliant sediment remediation projects previously implemented in the Puget Sound region. It is therefore anticipated that all of the remedial alternatives can be designed and implemented to comply with ARARs.

Management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste) are all largely procedural and influence the handling and disposal of materials. The ARARs may render implementation more complex but have negligible influence on whether a remedial alternative is feasible.

Resource protection requirements (e.g., habitat preservation, mitigation) do not pose a fundamental obstacle to the design and implementation of the remedial alternatives. Each alternative has the same remediation for the former shipway and shoreline and intertidal habitat

areas, and this remediation would be designed to result in no net loss of aquatic habitat area over time.

Clean Water Act 404 dredge and fill requirements can be met for all remedial alternatives. As with previous regional CERCLA remediation projects, the EPA would evaluate the selected alternative for substantive compliance with 404(b)(1) and Rivers and Harbors Act Section 10 requirements. Specific design elements would ensure these requirements are satisfied.

13.2.2.5 Summary of Compliance with ARARs

Alternative 1 does not satisfy the threshold requirement of complying with ARARs. Alternatives 2, 3, and 4 comply with ARARs with institutional controls.

Natural background PRGs are ARARs under MTCA for protection of human health via the seafood consumption pathway. The remedial alternatives (except Alternatives 2A4c and 4C) are not expected to achieve concentrations at or below such PRGs. Compliance with the MTCA ARARs is achieved by using institutional controls designed to reduce human exposure to resident fish and shellfish.

All ARARs must be met or waived under CERCLA upon completion of remedial actions. Compliance with some water quality standards may not be feasible, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs. The most common waiver for such circumstances is technical impracticability. The goal in all instances where predictions are that ARARs may not be achieved is to get as close as technically practicable to the ARAR and apply a waiver only to the extent necessary. A waiver will also be necessary for the MTCA requirement of using natural background for cases in which the RBTC is lower than natural background (i.e., PCBs, cPAHs, lead, and arsenic).

13.3 PRIMARY BALANCING CRITERIA

Primary balancing criteria are used to weigh effectiveness and cost tradeoffs among alternatives. The alternatives were compared with regard to how well they satisfy the five balancing criteria designated by CERCLA and presented below.

13.3.1 Long-term Effectiveness and Permanence

General analysis factors considered during comparative evaluation of alternatives for long-term effectiveness and permanence are magnitude of residual risks and adequacy and reliability of controls.

13.3.1.1 Magnitude of Residual Risks

The remedial alternatives were evaluated for three types of residual risk: surface and subsurface residual contamination and contaminant mass removal.

Magnitude of Surface Sediment Residual Risks

The evaluation of residual risk for this criterion was presented in Section 12 and the results are compiled in Table 13-1 for the purpose of comparative analysis. All of the alternatives except Alternative 1 achieve similar residual surface sediment risk levels. Alternatives 2A4c and 4C rank the highest, but all scores are in the range of 8.9 for Alternative 2A1 to 10 for Alternatives 2A4c and 4C.

Magnitude of Subsurface Residual Risks

The magnitude of subsurface residual risks was qualitatively gauged as described in Section 12 using both the number of cores with CSL and SQS exceedances (Table 12-4) and by evaluating the residual concentrations remaining after the remedy (Figures 12-2 and 12-4 to 12-7). Table 13-1 summarizes the results as the number of sediment cores with concentrations above CSL or SQS that would remain after remediation and that are located within the top 3 feet of sediments in areas that are capped, dredged, or undergo ENR. Both the number of cores with CSL and SQS residuals are presented in this evaluation to show the different levels of residual sediment concentrations for the risk-driver COCs that remain at the RI sampling locations after the remedy.

Alternative 1 has the greatest potential for re-exposure because all subsurface contamination remains in place and no actions are taken to reduce the risks. Complete removal alternatives (i.e., Alternatives 4A, 4B, and 4C) show no to very low potential for re-exposure of contaminants because removal from large AOPA footprints (18 to 40 acres) removes most or all contaminated sediment from the Lockheed West Site area.

The potential for re-exposure is considered slightly higher for removal-focus alternatives (Alternative 3) and containment-focus alternatives (Alternative 2) than the complete removal alternatives. For Alternative 3, either the dredge depth or the dredge footprints are smaller than Alternative 4; therefore, the potential from re-exposure from subsurface contamination is slightly higher. Under Alternative 2, the material remains at the site but the potential for re-exposure is only slightly higher because caps are engineered to remain structurally stable under site-specific conditions. In comparison to capped areas, residual contamination beneath ENR and dredged areas (i.e., from dredge residuals) has greater potential for re-exposure because these technologies are not engineered to ensure isolation of buried contaminated sediments. Thus, the potential for subsurface sediment to be exposed by scour or future uncontrolled human disturbance is greater beneath ENR or dredged areas than in capped areas. The comparison is slightly different when seismic events are considered. The re-exposure potential of subsurface contamination due to seismic events is slightly higher for cap and ENR areas than the dredge areas. Based on seismic analysis findings (see Appendix H), the risk of potential seismic-induced disturbance of subsurface sediments and the potential hazard is higher for Alternatives 1, 2, 3A1, 3A2, and 3B than for Alternatives 3C and 4. The reason is that Alternatives 3C and 4 include removal of upper liquefiable layers, which would decrease the potential hazard due to liquefaction when the seismic activity occurs. The predicted hazards are less for a 100-year event than the 500- and 2,500-year events. The alternatives were qualitatively evaluated for potential risk for re-exposing remaining subsurface contamination due to seismic events in Table 13-1 and incorporated into scoring of re-exposure risk due to seismic events and the reliability of the technologies in Table 13-2. Re-exposure of subsurface contaminated sediments due to man-made and natural disturbances is likely to be localized and have limited effect on average sitewide concentrations. The scores for residual risk of re-exposure in Table 13-2 are based on the number of subsurface sediment cores remaining under dredge, cap, ENR, and unremediated areas listed in Table 12-4 compared to the baseline number of cores with exceedances of the SQS for the risk-driver COCs. Shallow cores with an SQS exceedance left in place in an area with no cap were given a factor of 1.0, the shallow cores left in place in an ENR area were given a factor of 0.7, and cores in a cap area were given a factor of 0.1. The factors reflect the potential for re-exposure of contamination from the subsurface. The difference between the baseline number of cores (28) and the sum of the number of cores multiplied by the factor for the depth of

contamination is divided by the baseline number of cores to provide a relative score for the risk of re-exposure. A score of 10 indicates that no shallow cores with a concentration above the SQS for a risk-driver COC were left at the end of construction whereas a score of zero indicates that all cores with some contamination above the SQS in the shallower subsurface were left in place. Alternative 4C gets the highest score of 10, 2A1 gets the lowest score of 6.6, and the other alternatives have scores between 6.9 and 9.3.

The scoring for re-exposure potential due to seismic events is based on the liquefaction-induced hazard estimates for 100-, 500-, and 2,500-year events. No Action and alternatives with cap (e.g., Alternatives 1, 2, 3A1, 3A2, and 3B) are predicted to experience moderate liquefaction-induced hazard (up to 9 feet of lateral spreading and 4 feet of settlement for the 2,500-year event). The same hazard for the alternatives without cap (Alternatives 3C and 4) is predicted to be low (up to 4.5 feet of lateral spreading and 2 feet of settlement for the 2,500-year event). A score of 10 indicates no hazard and zero indicates high hazard. An interpolation between the predicted hazard in cap, ENR, and unremediated areas versus dredged areas results in a score of 4.6 to 10 for low hazard alternatives (removal-focus and complete removal alternatives) and 4 for moderate hazard alternatives (containment-focus alternatives). The potential risk from other seismic-induced disturbance mechanisms (e.g., seismic slope stability failure or a large-scale flow slide failure) is the same for all alternatives and no differentiating scoring is therefore applicable.

In the long term, re-exposure of buried contamination by physical disturbances including seismic events would generally be confined to small, localized areas, which could cause localized risks to benthic organisms if left unrepaired for a significant period. Such disturbances would not significantly increase residual sitewide risks (i.e., direct contact and seafood consumption risks).

Magnitude of Contaminant Mass Removal

As shown in Table 13-1, Alternatives 4A, 4B, and 4C would remove the most contaminant mass (137, 181, and 195 metric tons, respectively), followed by Alternatives 3A1, 3A2, 3B, and 3C with mass removals in the range of 38 to 91 metric tons, and Alternative 2B, whose dredge to fit cap component would remove 24 metric tons. Refer to Sections 11 and 12 for more information on individual contaminant mass removals for each alternative. Contaminant mass removals for

each alternative are compared in Figures 13-3a and 13-3b. These graphics show that Alternative 3A1 would perform the best in removing total contaminant mass per the total dredge volume removed, closely followed by Alternatives 3B and 3C, and then Alternatives 2B, 3A2, 4A, 4B, and 4C. Table 13-2 provides the scores for the mass of contaminants removed; the alternative with the most contaminant mass removed was given the highest rating of 10 and the alternatives with no contaminant mass removal was given a score of zero.

13.3.1.2 Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage contaminated sediment that remains on-site after implementation. Remedial Alternatives 2 and 3 require long-term O&M monitoring and institutional controls to manage residual risks and the potential for recontamination. The relative magnitude and importance of these control components vary somewhat among the subalternatives and are related to the re-exposure potential of subsurface contaminated sediment under technology specific applications (i.e., caps, dredging, and in areas managed for ENR).

Table 13-2 scores measures of technology reliability. One measure is the area of active remediation (refer to Figure 13-1). This measure scores the alternatives based on the area of the Site addressed compared to the total acres of the study area.

A second reliability metric takes into account the type and combinations of technology used in the alternatives. The reliability of the technology rates the effectiveness of the different technologies to produce a long-term result. The scoring reflects how well the alternatives result in a permanent and irreversible remedy. Complete removal would be given a high score because the contamination would be permanently removed from the site, although partial dredging would leave some residuals on-site. Alternatives that leave contamination in place under an engineered cap would have a relatively high score because a cap is engineered to remain in place, while those alternatives that contain the contamination through ENR would have a lower ranking. However, the structural integrity of the capped areas may be disturbed due to seismic events and then require repair. The need for localized repair of ENR areas will be evaluated as appropriate. Based on the reliability of the technologies for the Site, weighting factors for each technology were applied—dredging received a factor of 9, capping received a factor of 8, and ENR a factor

of 5—and the alternatives were then scored according to the acres across which the technologies are applied against the total acres for the study area (40 acres).

Control of Dredge Residuals

All dredging projects leave behind some level of residual contamination immediately after completion of in-water work due to resettling of suspended sediments, subsequent disturbance and transport of the material, or material left behind in the dredge prism (NRC, 2007). Management of dredge residual is evaluated as a common remedy element in the development of remedial alternatives (Section 11) with a specific assumption that dredging is followed by a thin-layer application of sand to control residuals. Control of dredge residuals is incorporated into the comparative evaluation matrix in terms of the reliability of the alternative technologies implemented relative to the active remediation area.

Monitoring

Monitoring is required to verify performance of the remedy and achievement of project RAOs. Monitoring during construction is necessary regardless of the alternative. Once PRGs associated with RAOs are achieved, differences in the adequacy and reliability of monitoring are minor among the alternatives. However, the scope and duration of monitoring differ among the alternatives based on the technology components, such as dredge, cap, and ENR, and the need for collection of more project-specific O&M monitoring data. To differentiate among the alternatives, the monitoring evaluation factor is qualitatively assessed in terms of whether the remedial alternatives have large, moderate, or small surface areas that require technology-specific monitoring during the O&M period of 30 years set for this FS (Table 13-1).

Alternative 2A1, managing 18 acres of cap and ENR, needs moderate monitoring compared to a moderate to high monitoring need for alternatives managing 30 acres (Alternatives 2A2, 2A2a, 2A2b, 2A4b, 3A1, 3A2, 3B, and 3C) and a high monitoring need for alternatives managing 40 acres (Alternatives 2A3, 2A4c, and 2B). Alternatives 4A and 4B require moderate to high monitoring due to dredge backfill areas of 18 and 30 acres, respectively. Alternative 4C would not need any long-term O&M monitoring. Post-removal action confirmation sampling and analysis will be conducted after construction to provide direct measurement of residual conditions. Corrective actions will be taken if dredged areas fail to meet performance requirements. Relative scores for monitoring considerations are presented for each alternative in

Table 13-2. This metric is rated based on the number of acres of capping and ENR: alternatives that have no capping or ENR are given a rating of 10, those alternatives with 40 acres of capping and ENR are given a rating of zero, and those in between are directly proportional to the difference.

Institutional Controls

Institutional controls are a required element for all alternatives except Alternative 4C. None of the alternatives, except Alternatives 2A4c and 4C, can achieve the PRGs for total PCBs and cPAHs that are set to natural background for the human seafood consumption scenario. Therefore, remaining risks to the community from seafood consumption must be managed by institutional controls through seafood consumption advisories and a public education/outreach program. The Washington State Department of Health publishes seafood consumption advisories for Washington State. Regardless of the selected remedy, it is likely that any remedial action that achieves PRGs will reach sediment concentrations above the PRGs in the long term due to a variety of recontamination sources (see Section 5.2). The recontamination potential of all alternatives is the same and does not represent a differentiating factor for comparative evaluation of the alternatives. In Table 13-2, four metrics were used to score alternatives regarding the level of institutional controls required: long-term requirement for controls, future use limitations, Port development limitations, and acres of ENR.

For the long-term requirement, alternatives requiring institutional controls related to capping were rated at a 3 while alternatives requiring institutional controls other than those related to capping were rated a 7. Alternative 4C was rated 10 because it does not require institutional controls related to the Site sediments. The alternatives do not differ in the scope and duration of this control once RAOs are achieved. The public education/outreach effort would be developed with participation from local governments, Tribes, and other community stakeholders.

The scale of institutional controls regarding notification of waterway users due to potential future-use restrictions increases based on the proposed cap area. Table 13-1 provides qualitative correlations regarding future use restrictions: the restrictions are considered very low to low for cap areas of 1.3 acres to 6.3 acres (Alternative 3); moderate for a cap area of 10.3 acres (Alternatives 2A1, 2A2a, 2A3, and 2B); moderate to high for a cap area of 18 acres (Alternatives

2A2b and 2A4a); and high for a cap area of 30 to 40 acres (Alternatives 2A4b and 2A4c). Complete removal alternatives do not include any cap area and would not cause any future use restrictions. The same correlation is also reflected in relative scorings presented Table 13-2: Alternatives 4A, 4B, and 4C get the highest score of 10; Alternative 2A4c gets the lowest score of zero due to the 40 acres of cap; and the other alternatives are scored in between. See the assigned scores for each alternative in Table 13-2 (the row "future use limitations [relative to acres capped]" within the "Primary Balancing Criteria / Long-Term Effectiveness and Permanence / Adequacy and reliability of controls" portion).

The Port owns the upland area near the Site and part of the marine area of the site to the Inner Harbor Line; it also manages other areas under its Port Management Agreement with DNR. Current known potential plans for the Port include the expansion of the Terminal 5 pier to the north along the West Waterway and vessel and barge moorage along the north of the site. For the metric regarding Port use limitations, alternatives that specifically address the area of the potential Terminal 5 expansion are rated as 10 or near 10 whereas alternatives that leave contamination in place or place a cap in the area are given a rating near zero. See the assigned scores for each alternative in Table 13-2, the row "Port future development limitations" within the "Primary Balancing Criteria / Long-Term Effectiveness and Permanence / Adequacy and reliability of controls" portion). The long-term effectiveness of ENR is more uncertain and therefore considered to be relatively lower than for removal and/or capping. As such, ENR has some potential limitations for long-term effectiveness and will require monitoring. In Table 13-2, alternatives are given a score based on the acres of ENR and the unremediated area within the study area boundary as part of the alternative, with a rating of zero given to alternatives with 30 acres of ENR and those with zero acres given a rating of 10.

As noted above, Table 13-2 provides scores for the future development limitation metric for the Port. Alternatives 4A, 4B, and 4C get the highest score of 10 by providing a dredge-only remedial action, closely followed by Alternatives 3B and 3C where dredging in former dry dock areas would allow unencumbered Port developments in front of Terminal 5. The rest of alternatives are scored zero because they would limit the Port's future development plans by capping over different AOPAs.

13.3.1.3 Summary of Long-Term Effectiveness and Permanence

With the exception of Alternative 1, the remedial alternatives meet the threshold criterion for overall protection of human health and the environment by achieving the four RAOs by implementation of the engineered remedy and application of appropriate institutional controls and by providing monitoring to ensure the PRGs associated with the RAOs are achieved. Again with the exception of Alternative 1, the residual risks from surface sediment are similar among the alternatives with slight variations in re-exposure potential as discussed above.

Long-term O&M monitoring is a reliable control. Sampling methods and analytical techniques are sufficiently advanced to enable collection of representative data for purposes of assessing long-term remedy performance following achievement of PRGs associated with RAOs. The alternatives differ in the scope and duration of long-term O&M monitoring, which are in proportion to the total surface area designated for capping, ENR, and dredge footprints.

Adequate controls to manage dredge residuals can be included in engineering design requirements and are discussed as a common remedy element of the remedial alternatives developed in this FS (refer to Section 11.3). The scale of dredge residuals management component is directly correlated with the proposed dredge footprints.

All active alternatives, except Alternative 4C, have similar seafood consumption advisories and a public education/outreach program. Institutional controls are not needed for Alternative 4C, under which protection of human health through seafood consumption (i.e., RAO1 PRGs) is achieved through complete removal; however, as discussed above, the existing regional consumption advisories would still apply. The reason for this is there will be restrictions on the number of fish that can be consumed even if the cleanup meets the PRGs as they (natural background concentrations in most cases) are higher than the RBTCs. Alternatives 2 and 3 require governmental controls (i.e., notification of waterway users), proprietary controls (e.g., deed restrictions, restrictive covenants), and enforcement and permit tools for areas with residual contamination remaining above protective levels through capping and ENR. See Section 12.1.2.1 for general discussion of institutional controls and Sections 12.3.1, 12.4.1, and 12.5.1 for discussion of required institutional controls under Alternatives 2, 3, and 4, respectively. The

scale of the controls regarding notification of waterway users due to future-use restrictions is based on the proposed cap area.

Alternative 1 has the lowest relative score (2.9) for long-term effectiveness and permanence because it does not provide any long-term monitoring to ensure reliability of controls and leaves the largest amount of subsurface contamination in place. Alternatives 4A, 4B, and 4C get the highest scores under long-term effectiveness and permanence criteria (7.2 to 9.9). The other alternatives have relative scores between 4.1 and 6.0 based on the amount of contaminated sediments removed (i.e., applicable to Alternatives 2B, 3A1, 3A2, 3B, and 3C), the scale of restrictive controls, and the extent of monitoring and maintenance requirements.

13.3.2 Reductions in Toxicity, Mobility, and Volume through Treatment

This criterion assesses the degree to which site media are treated to reduce the toxicity, mobility, or volume of site contaminants permanently and significantly. There would be no reduction of toxicity, mobility, or volume through treatment with any of the alternatives because no treatment would be implemented. Some reduction in toxicity, mobility, and volume would occur through removal or physical isolation of the most contaminated sediment.

13.3.3 Short-Term Effectiveness

This evaluation criterion addresses the effects of the alternative during the construction and implementation phase. Under this criterion, alternatives are evaluated for their effects on human health and the environment during implementation of the remedial action including impacts on the community, workers, and the environment. Typically, this criterion also considers the time required for each alternative to achieve the PRGs associated with the RAOs. All active remedial alternatives would achieve PRGs associated with the RAOs in the remediated areas at the completion of construction. Therefore, comparative evaluation of short-term effectiveness was focused on evaluation of protection of workers, community, and environment during construction.

13.3.3.1 Protection of Workers and Community during Construction

Short-term impacts to both workers and the community are largely proportional to the construction period and due to the volume of contaminated material removed, handled, and

transported. For workers, activities on the construction job site (e.g., from operation of heavy equipment) pose the greatest risk of physical injury. Risk to workers from exposure to site-related contaminants is generally considered low and manageable through established health and safety requirements for hazardous materials site work but the potential for exposure and injury increases in proportion to the duration of construction. Similarly, impacts to the community increase with the amount and duration of construction. The potential for physical injury to both workers and the community is primarily a function of accidents associated with road-transport of contaminated sediment and clean import material to and from the Site. This potential is related to the amount of truck and train traffic anticipated. Table 13-1 summarizes estimates of truck and train miles traveled under each alternative. Assumptions of truck and train miles estimates are included in Appendix G. Transportation-related impacts would be managed in part with traffic control plans developed during remedial design.

Other community impacts from transportation and heavy equipment operations are air emissions (e.g., PM_{10}, a respiratory irritant), noise, and nighttime illumination of operations. Also, consumption of seafood caught at the Site during construction presents short-term risks to the community because concentrations of COCs in resident seafood are likely to be higher during construction as a result of contaminated sediment resuspension and biological uptake.

Alternatives 2 and 3 are expected to be completed in one construction season with the exception of Alternative 3C under which in-water construction activities may require two construction seasons to complete, resulting in lower expected short-term risks to workers and the community. Complete removal alternatives have an estimated construction period of 3 to 9 years and would have higher short-term impacts to the community and workers. Table 13-2 provides the scores of each alternative, calculated correlated to the years of construction of each alternative, with zero years (No Action alternative) receiving a score of 10 and 9 years (Alternative 4C) given a score of zero. Table 13-2 also provides a rating relative to the volume of material removed, handled, and transported for comparative evaluation purpose. Alternative 4 scores less than Alternatives 1, 2, and 3 because it handles a larger amount of dredge material. Scoring is correlated to the volume material removed, handled, and transported under each alternative.

13.3.3.2 Protection of Environment during Construction

Cleaning up the Lockheed West Site will have environmental impacts that can be grouped into the categories of atmospheric emissions, ecological impacts, and resource consumption. In general, removal-focus (Alternative 3) and complete removal (Alternative 4) alternatives have greater short-term impacts in all of these categories than the containment-focus alternatives with similar AOPAs (see Table 13-1).

Larger actively remediated footprints increase the areal extent of short-term disturbances to the existing benthic community and other resident aquatic life. Concentrations of bioaccumulative chemicals (e.g., total PCBs) may increase in the tissues of aquatic organisms during the construction phase of removal-focus and complete removal alternatives. Longer construction time frames increase air emissions and noise. Air emissions include components with local environmental impacts (e.g., sulfur oxides and nitrogen oxides emissions), those which can cause respiratory problems (PM_{10}), and those with global impacts (CO_2 and other greenhouse gases). In Table 13-1, gas emissions include estimates of CO_2 emissions, the most important greenhouse gas, and PM_{10} calculated using the same emissions factor approach as recently performed for the LDW FS (AECOM, 2010). Carbon monoxide, nitrogen oxides, and sulfur oxides emissions were not estimated in this FS. The details of short-term effectiveness metrics and sustainable best management practices are provided in Appendix G.

The remedial alternatives consume quarry materials such as sand and gravel to satisfy the varying requirements for capping, backfilling, habitat material, ENR, and management of dredge residuals (Table 13-1). Removal-focus and complete removal alternatives (Alternatives 3 and 4) consume less material than the containment-focus alternatives (Alternative 2). Alternative 2A4c has the greatest material demand primarily because it has an AOPA of the study area boundary and the largest capping footprint compared to other containment focus alternatives.

Complete removal alternatives (Alternatives 4A, 4B, and 4C) require more landfill space in increasing scale based on the AOPAs than other removal-focus alternatives with smaller AOPAs (Alternative 3) and containment-focus alternatives (Alternative 2). Although Alternatives 2A1, 2A2a, 2A2b, 2A3, 2A4a, 2A4B, and 2A4c are containment-focused, they still require landfill space due to the removal activities associated with the common remedy element of former

shipway, shoreline, and intertidal habitat remediation. Alternative 2B has a dredge component to fit the conventional cap and requires landfill space for upland disposal. All of the alternatives dredge some volume of material and therefore consume landfill space (Table 13-1).

Alternatives 4A, 4B, and 4C have longer construction periods, consume the greatest amount of natural resources, generate the most transportation-related impacts, produce the greatest emissions, and create the longest periods of bioaccumulation and exposure in resident species. These alternatives rank relatively low due to high short-term impacts to the community and the environment. Alternatives 2A1, 2A2a, 2A2b, 2A3, and 2A4a score relatively high because the short-term community and environmental impacts last for a much shorter time. The remaining alternatives (i.e., Alternatives 2A4b, 2A4c, 2B, 3A1, 3A2, 3B, and 3C) have moderate scores for environmental impacts.

13.3.3.3 Summary of Short-Term Effectiveness

Alternatives with longer construction times and that handle larger amounts of contaminated material present proportionately larger risks to workers, the community, and the environment. Longer construction periods increase equipment and vehicle emissions, noise, and other resource use. Larger actively remediated footprints increase the short-term disturbance of the existing benthic community and other resident aquatic life and generate more releases of bioavailable chemicals over a longer period of time. The comparative ranking of each alternative for the short-term effectiveness criterion is based on differences in construction time and the quantity of dredge removal because the nature of dredging work and ancillary technologies contribute the most to the short-term effectiveness metrics, as discussed above. Alternative 1, No Action, has the highest score of 10 in this category. Alternative 4C, the most extensive complete removal alternative, gets the lowest score (1.3) followed by Alternative 4B and 4A (4.2 and 7.4 respectively). The other alternatives scored higher (8.4 to 9.3) due to their short construction period and fewer or no dredge components (Table 13-2).

13.3.4 Implementability

This evaluation criterion is used to consider the technical and administrative feasibility of implementing the remedial alternatives and availability of services and materials. The evaluation is focused on technical and administrative implementability because resources for the remedial

technologies are available from multiple vendors and procurable through competitive bidding in the Pacific Northwest.

In general, the potential for technical problems and schedule delays increases in direct proportion to duration and complexity of the alternatives. Alternatives with removal components (Alternatives 2B, 3, and 4) have more complex technical and administrative (e.g., coordination with agencies) implementability issues due to the complexity of dredging and ancillary technologies (i.e., transloading, transporting, water management, disposal, monitoring, and residuals management). Alternatives with larger AOPAs that are designed to remove large volumes of material and require a longer construction period (Alternatives 4A, 4B, and 4C) have a comparatively higher potential for problems and delays than the alternatives with smaller active footprints and designed to remove smaller volumes of material and have shorter construction time (Alternatives 2B, 3A1, 3A2, 3B, and 3C). This is reflected in Tables 13-1 and 13-2 using actively remediated area and dredge volume as metrics.

In this context, Alternatives 2A1, 2A2a, 2A2b, 2A3, 2A4a, 2A4B, and 2A4c have a low potential for technical and administrative difficulties and schedule delays. From the operational reliability perspective, the alternatives with dredging components are again more challenging than the containment-focus alternatives following the scale given in Table 13-2. This is mainly due to residuals management, which poses a concern for reliability insofar as additional passes or expansions of the limits of dredge footprints may be required.

The required institutional controls for each alternative are technically implementable. Administrative implementability of institutional controls requires cooperation of the implementing agencies and local Native American tribes, as well as public acceptance and commitment from the public, site users, and site owners. Management and ownership status of the Site requires coordination between EPA, DNR, and the Port during selection, design, and implementation of the institutional controls. The implementation of long-term maintenance of the cap requires coordination with the Muckleshoot and Suquamish Tribes, Port, and DNR about the implications on future aquatic land use and/or tribal treaty rights (i.e. fishing rights on all U&A areas). Refer to Section 10.4.2.2 for more discussion on implementability of institutional controls. This Site is a tribal U&A area, and therefore the future use restrictions related to cap

areas will be minimized or eliminated during design. For the purpose of this FS, these restrictive institutional controls and their administrative implementability were incorporated into the comparative evaluation in Table 13-1. The institutional controls applicable to cap areas were considered to have low to moderate implementability while the institutional controls applicable to dredge, ENR, and unremediated areas within the study area boundary would have moderate implementability due to the challenges of implementing seafood consumption advisories, education programs, and public outreach.

In general, the containment-focus alternatives have slightly higher technical and administrative implementability than the removal-focus and complete removal alternatives. The scaling is based on the actively remediated areas, complexity of dredging compared to capping and ENR, the duration of the remedial construction, and the administrative implementability of institutional controls. Consistent with this discussion, Alternative 2A1 is scored highest at 8.7 in this category followed by Alternatives 2A4a and 2A2a (8.5 and 8.3 respectively) while other containment- and removal-focus alternatives are scored between 7.1 and 8.1 and Alternatives 4A, 4B, and 4C get lower scores, with the lowest being Alternative 4C (0.6). These rankings are compiled in Table 13-2 and incorporated into the total benefits and weighted benefits comparative analysis of the alternatives.

13.3.5 Cost

This assessment evaluates the capital costs (engineering, construction, and supplies) and annual or periodic costs (O&M costs, monitoring, institutional controls, and ongoing administration) of each alternative. Costs for the alternatives range from $17.0 million (Alternative 2A1) to $302.8 million (Alternative 4C). Detailed cost estimates for each remedial alternative are presented in Appendix F and summarized in Tables 13-1 and 13-2 and Figure 13-4. These estimated costs include assumptions for long-term monitoring, institutional controls, and contingency actions; however, they do not include anticipated costs associated with future use restrictions (e.g., third-party settlement costs) for the capped area. Institutional controls related to future use restrictions have been incorporated into the evaluation of the adequacy and reliability of controls under long-term effectiveness and permanence and implementability. These future use restrictions will be minimized during the design of the remedy because the Site is a tribal U&A area and the remedy should be designed to reduce conflicts or restrictions on tribal treaty fishing rights or other treaty

protected rights. Cost data are presented for informational purposes and are not incorporated into the comparative analysis evaluation as a preferred remedial alternative determination factor.

Figure 13-4 shows the weighted criteria rating score for each alternative (as shown in Table 13-2) with an overlay of total cost. The weighted criteria rating scores for the alternatives have a narrow range of 5.4 to 7.1, which indicates that the higher cost alternatives show little or no increase in overall benefit with additional costs. Figure 13-5 shows the average criteria rating score for the alternatives along with the total cost. The average criteria rating scores have a similar narrow range as the weighted criteria rating scores indicating little or no increase in overall benefit with additional costs.

13.4 MODIFYING CRITERIA

Modifying criteria are state acceptance and community acceptance and may be used to modify aspects of the preferred alternative when preparing the ROD for the remedial alternative. The proposed alternative for cleanup of the Lockheed West Site will be identified in the EPA Proposed Plan and that document will also identify the formal public comment period. The EPA will evaluate state, tribal, and community acceptance in the final decision document following the public comment period on the FS and on EPA's proposed plan. For these reasons, Table 13-1 and 13-2 do not include evaluation of alternative ranks for the modifying criteria.

13.5 COMPARATIVE ANALYSIS SUMMARY AND IDENTIFICATION OF A BEST-SUPPORTED ALTERNATIVE

This section discusses some of the key conclusions related to protecting human health and the environment by comparing remedial alternatives to the CERCLA criteria for remedial alternative selection. Key similarities and differences among the alternatives and how they compare are summarized in Section 13.5.1. Based on the detailed descriptions and the comparative analysis of alternatives, Section 13.5.2 discusses the identification and selection of a best-supported remedial alternative.

13.5.1 Summary of the Comparative Analysis

The key points of the comparative analyses and performance of the remedial alternatives discussed in this section are summarized here. The comparative analysis evaluation was

performed under nine CERCLA criteria (two threshold criteria, five balancing criteria, and two modifying criteria). As discussed in Section 13.4, the last two modifying criteria, state/tribal and community acceptance, will be evaluated by EPA after the FS is completed and include consideration of formal public comments on the proposed plan.

13.5.1.1 Overall Protection of Human Health and the Environment

Alternative 1 does not achieve this threshold criterion. Alternatives 2, 3, and 4 provide adequate overall protection to human health and the environment, achieving RAO 1 through implementation of the engineered remedy and application of institutional controls, and achieving PRGs associated with RAOs 2, 3, and 4 through implementation of the engineered remedy. Alternative 4C achieves PRGs for all RAOs through implementation of the engineered remedy only. All remedial alternatives produce a clean surface over the areas remediated at the end of construction, achieving PRGs for all RAOs for the short term. Over the long term, the surface and near surface sediments will reach an equilibrium concentration through mixing as described in the ENR application for the Site. Some deposition of new sediment over the post-construction surface is expected to occur. The long-term concentrations for COCs at the Site are expected to be in the range between the natural background levels and the concentrations found in the Elliott Bay region.

Alternatives that dredge or cap a larger surface area have a lower potential for subsurface contamination to be re-exposed by erosion due to wind and wave action or mechanical disturbances (e.g., propeller scour). Alternatives that apply a cap and ENR over a larger surface area have a higher potential for subsurface contamination to be re-exposed by seismic events. Re-exposure of subsurface contaminated sediment is likely to be localized and have limited effect on sitewide averages.

Alternatives 2, 3, and 4 can be implemented in a manner that protects workers, the community, and the environment. Alternatives with longer construction periods have proportionately greater short-term environmental impacts.

13.5.1.2 Compliance with ARARs

Alternative 1 does not satisfy the threshold requirement of complying with ARARs. Alternatives 2, 3, and 4 comply with ARARs by including institutional controls to reduce human exposure to fish and shellfish.

Natural background PRGs for RAO 1 in sediment are ARARs under MTCA for protection of human health via the seafood consumption pathway. The remedial alternatives (except Alternatives 2A4c and 4C) are not expected to achieve concentrations at or below these PRGs, which are set to natural background concentrations. Compliance with the MTCA ARARs is achieved by using institutional controls designed to reduce human exposure to resident fish and shellfish.

13.5.1.3 Long-term Effectiveness and Permanence

Alternative 1 has the lowest relative score (2.9) for long-term effectiveness and permanence because it leaves the largest amount of subsurface contamination in place and does not provide any long-term monitoring to ensure reliability of controls. Alternatives 4A, 4B, and 4C get the highest scores under long-term effectiveness and permanence criteria (7.2 to 9.9). The other alternatives have relative scores between 4.1 and 6.0 based on the mass of contaminants removed (i.e., applicable to Alternatives 2B, 3A1, 3A2, 3B, and 3C), re-exposure potential from remaining subsurface contamination, re-exposure risk due to a seismic event, the scale of restrictive controls required in the long term and related to future use limitations, and the extent of monitoring and maintenance requirements.

13.5.1.4 Reductions in Toxicity, Mobility, and Volume through Treatment

There would be no reduction of toxicity, mobility, or volume through treatment with any of the alternatives, because no treatment would be implemented. Some reduction in toxicity, mobility, and volume would occur through removal or physical isolation of the most contaminated sediment.

13.5.1.5 Short-term Effectiveness

All active alternatives achieve the PRGs associated with the RAOs for the remediated areas at the end of the construction period. Generally, the alternatives that represent the least impact to

the community, site workers, and the environment during their implementation and that achieve protectiveness in the shortest time are scored most favorably. More dredging involves the most construction, handling, and transportation activities and is considered the least protective of workers. More dredging represents the greatest risk to the environment and the least protective of the community because dredged material will need to be transported through the community to an off-site landfill by barge, truck, and rail, increasing the potential for physical hazards.

Alternative 1, No Action, has the highest score of 10 in this category because no active remedial actions would be performed. Alternative 4C, the most extensive complete removal alternative, gets the lowest score (1.3) followed by Alternatives 4B and 4A (4.2 and 7.4, respectively). Other containment-focus and removal-focus alternatives scored higher (8.4 to 9.3) due to their short construction period or fewer or no dredge components, which would therefore result in fewer short-term impacts to the Site workers, community, and environment (see Table 13-2).

13.5.1.6 Implementability

Containment-focus alternatives have higher technical implementability than the removal-focus and complete removal alternatives. Alternatives with cap (containment-focus and removal-focus) have a lower administrative implementability than the complete removal alternatives due to administrative difficulties of applying institutional controls to cap areas. Removal-focus and complete removal alternatives exhibit the least relative technical implementability performance because they involve more on-site and off-site construction activities during dredging, handling, transportation, and disposal of the sediments. Consistent with this discussion, Alternative 2A1 is scored highest (8.7) in this category followed by Alternatives 2A4a and 2A2a (8.5 and 8.3 respectively) while other containment- and removal-focus alternatives are scored between 7.1 and 8.1 and Alternatives 4A, 4B, and 4C get lower scores, with the lowest being Alternative 4C (0.6).

13.5.1.7 Cost

Costs for the alternatives range from $17.0 million to $302.8 million. Detailed cost estimates for each remedial alternative are presented in Appendix F and summarized in Tables 13-1 and 13-2.

13.5.2 Selection of Best-Supported Alternative

This section discusses the rationale for identifying and selecting a best-supported alternative and provides a general description of the best-supported alternative. This determination is based on both the individual evaluations of the remedial alternatives against the CERCLA evaluation criteria (Section 12) and the comparative evaluation of the remedial alternatives presented above.

13.5.2.1 Rationale for Recommendation

Table 13-2 summarizes the criteria ratings for Alternatives 1 through 4. Alternative 1 failed to meet CERCLA threshold criteria but was retained for comparative purposes as the baseline conditions. Considering all of the rating criteria, the total weighted rating scores for the remedial alternatives range from 5.4 to 7.1 (Figure 13-4) and average unweighted rating scores for the remedial alternatives range from 3.9 to 7.5 (Figure 13-5). This narrow range is attributable primarily to two key factors: 1) the predicted outcomes are similar for all alternatives and 2) differences between the alternatives for individual criteria are diminished when those criteria are averaged to calculate total benefits. However, the results demonstrate the fundamental differences between the alternatives. More dredging does not necessarily result in higher overall scores because of higher short-term impacts to the workers, community, and environment and lower technical and administrative feasibility. More reliance on isolation through capping can result in higher scores due to its benefits in reducing short-term impacts and having higher technical and administrative feasibility. Figure 13-4 shows the weighted criteria rating score for each alternative (also summarized in Table 13-2) with an overlay of cost. The weighted criteria rating score for the alternatives indicates that the higher cost alternatives show little or no increase in overall benefit with additional costs.

Figure 13-6 summarizes each alternative's remedial technologies (i.e., dredging, capping, and ENR), the size of the active remedial footprint (acres), the removal volumes (cubic yards), the weighted benefit score, and cost. This figure demonstrates that regardless of the remedial technology, the remedial footprint, or dredge volume, there is proportionally little difference in the overall benefits of the alternatives. Any differences in overall protectiveness of Alternatives 2, 3, and 4 are largely in the context of short-term and long-term effectiveness (Tables 13-1 and 13-2). Similar to Figure 13-4, Figure 13-7 presents the weighted benefits per unit cost for each alternative and demonstrates a general trend for declining cost/benefit ratio as the alternative's

costs increase. This is expected because, as described above, all alternatives score similarly in criteria ratings regardless of cost. The containment-focus alternatives generally have slightly greater benefit per unit cost than similarly priced removal-focus alternatives. As shown in Figure 13-7, Alternative 2A1 appears to be the lowest cost alternative with the highest benefit; however, there are some limitations associated with this alternative in the degree to which it meets RAO 2 and 4 PRGs (Table 12-3).

Based on the detailed comparative evaluation of the remedial alternatives, Alternative 2A2a is identified as the best-supported alternative at the Lockheed West Site because of the following:

- Alternative 2A2a achieves site-specific PRGs associated with RAOs and ARARs through implementation of the engineered remedy and application of institutional controls. The remedy produces a clean surface over the areas remediated at the end of construction achieving the PRGs for all RAOs in the short-term. Over the long term, the surface and near surface sediments will reach an equilibrium concentration through mixing as described in the ENR application for the Site. Some deposition of new sediment over the post-construction surface is expected to occur. The long-term concentrations for COCs at the Site are expected to fall between the natural background levels and the concentrations found in the Elliott Bay region.
- All active alternatives, except Alternative 4C, have similar seafood consumption advisories and a public education/outreach program. To meet RAO 1, institutional controls are needed for Alternative 2A2a, under which 93 percent progress toward meeting PRGs for protection of human health through seafood consumption (i.e., RAO1 PRGs) is achieved through capping and ENR remedial activities. However, as discussed above, regardless of the selected alternative the existing regional consumption advisories would still apply. The reason for this is there will be restrictions on the number of fish that can be consumed since the PRGs (natural background in most cases) are higher than the RBTCs.
- Alternative 2A2a achieves the PRGs associated with RAOs 2, 3, and 4 through implementation of the engineered remedy at the end of construction and in the long term.
- Alternative 2A2a scores high under the CERCLA balancing evaluation criteria (i.e., long-term effectiveness and permanence, short-term effectiveness, implementability, cost) with an average ranking of 7.3 where the other alternatives have an average ranking in the range of 3.9 to 7.5.

- The remedy includes former shipway area remediation, shoreline remediation, shoreline stabilization, and intertidal habitat restoration and improvements in addition to the subtidal remediation. Shoreline remediation incorporates removal, capping, and backfilling to allow tribal fishing and clamming.
- There is low to moderate potential for re-exposure of remaining subsurface contamination. There is moderate hazard predicted due to seismic events. It is feasible to repair the cap if such damage occurs. The need for localized repair of ENR areas will be evaluated as appropriate. Localized impacts are unlikely to affect sitewide average concentrations.
- The capped area footprint and associated restrictions on potential future uses are limited to the former dry dock areas. The cap would encumber but does not preclude reasonably anticipated future land use issues provided by the Port and DNR.
- Potential future use restrictions related to cap areas can be minimized during design by increasing the thickness of the cap to allow anchoring and grounding of small vessels and by coordinating with the Muckleshoot and Suquamish Tribes, Port, and DNR.
- Short-term effectiveness risks to the Site workers, community, and environment are low.
- Technical and administrative implementability during construction is high.
- Adequacy and reliability controls are well-established to ensure the integrity and the performance of the remedy through combination of monitoring, maintenance, and institutional controls that would be designed and implemented in the next 30 years.
- The alternative has the additional benefit of having the smallest environmental footprint of remedial action after Alternative 2A1 in terms of greenhouse gas emissions, fuel consumption, use of natural resources, and landfill volume requirements.
- Alternative 2A2a achieves equal overall benefits relative to other alternatives at a lower cost, providing the most cost-effective and protective remedy.

13.5.2.2 Description of the Best-Supported Alternative

Under Alternative 2A2a, conventional sediment capping and ENR would be used to contain contaminated sediments within the remedial action area, creating a clean surface suitable for re-establishment of aquatic biota. In areas that are capped, the cap would be of sufficient thickness and gradation to ensure isolation of impacted sediments and to withstand natural and vessel-related erosion forces. The alternative involves:

- Conventional capping over the areas defined by the risk-drivers to the surface CSL footprint (10.3 acres) and ENR over the remaining area to the Urban AOPA footprint (19.7 acres);
- Performing former shipway area remediation, shoreline remediation, shoreline stabilization, and intertidal habitat restoration and improvements (about 2 acres and removal/replacement of approximately 10,000 cubic yards);
- Long-term monitoring O&M program to verify performance of the cap and to respond to potential cap damage; and
- Institutional controls—public outreach, education, and seafood consumption advisories (as part of regional Elliott Bay advisories); proprietary controls (e.g., easement of cap area); monitoring and notification of waterway users, which would be minimized or eliminated during design; and site registry to apply to conventional capping area.

Figure 13-8 illustrates active remedial actions of the best-supported alternative.

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Table 13-1. Comparative Evaluation of Remedial Alternatives

Evaluation Criteria					Remedial Alternative															
					1	2A1	2A2a	2A2b	2A3	2A4a	2A4b	2A4c	2B	3A1	3A2	3B	3C	4A	4B	4C
Overall Protection of Human Health and the Environment	Summary of Long-Term Effectiveness and Permanence (See Long-Term Effectiveness Section Below for Details)	Magnitude of Residual Risk	RAO 1: Human Seafood Consumption Average performance towards reaching RAO 1 PRGs from mean baseline conditions (%) [1/]		17%	89%	93%	97%	94%	93%	99%	100%	96%	95%	94%	93%	94%	95%	97%	100%
			RAO 2: Human Health Direct Contact Risk threshold achieved [2/]		n/a	$\leq 1 \times 10^{-5}$ [3/]	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$ [3/]	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$
			RAO 3: Benthic Organisms Lockheed West surface area predicted to comply with SQS as percent of total study area (%)		n/a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
			RAO 4: Ecological Health Risk threshold achieved (HQ for consumption of seafood)		n/a	<1 [4/]	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
			Achievement of RAOs		Not expected to achieve RAOs.	PRGs are not achieved for RAO 1, except 2A4c and 4C; however RAO 1 is achieved for the other alternatives through a combination of active remediation and institutional controls. PRGs associated with RAOs 2, 3, and 4 are achieved at completion of construction.														
			Potential for Re-Exposing Remaining Subsurface Contamination [5/]		Largest amount of subsurface contamination and greatest potential for re-exposure.	Low to moderate potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (9 cores remaining after construction with CSL [2 of 9] or SQS [7 of 9] exceedences <3 ft in ENR and no action areas).	Low to moderate potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (9 cores remaining after construction with CSL [2 of 9] or SQS [7of 9] exceedences <3 ft in ENR areas).	Low potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (4 cores remaining after construction with SQS exceedences <3 ft in ENR areas).	Low to moderate potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (9 cores remaining after construction with CSL [2 of 9] or SQS [7 of 9] exceedences <3 ft in ENR areas).	Low potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (4 cores remaining after construction with SQS exceedences <3 ft in no action area).	Low potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (2 cores remaining after construction with CSL or SQS exceedences <3 ft in ENR areas).	Very low potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (no cores remaining after construction with CSL or SQS exceedences <3 ft in ENR areas).	Low to moderate potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (9 cores remaining after construction with CSL [2 of 9] or SQS [7 of 9] exceedences <3 ft in ENR areas).	Low to moderate potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (9 cores remaining after construction with CSL [3 of 9] or SQS [6 of 9] Exceedences <3 ft in ENR and dredge areas).	Low potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (5 cores remaining after construction SQS exceedences <3 ft in ENR and dredge areas).	Low to moderate potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (11 cores remaining after construction with CSL [4 of 11] or SQS [7 of 11] exceedences <3 ft in ENR and dredge areas).	Low to moderate potential for re-exposure. Localized impacts unlikely to affect sitewide average concentration (11 cores remaining after construction with CSL [4 of 11] or SQS exceedences [7 of 11] <3 ft in ENR and dredge areas).	Very low potential for re-exposure. No designated ENR areas. Less amount of residual subsurface contamination (4 cores remaining after construction with SQS exceedences <3 ft in non-dredged areas).	Very low potential for re-exposure. No designated ENR areas. Least amount of residual subsurface contamination (2 cores remaining after construction with SQS exceedences).	No potential for re-exposure. No designated ENR areas. Least amount of residual subsurface contamination (no cores remaining after construction with CSL or SQS exceedences).
			Potential Risk for Re-Exposing Remaining Subsurface Contamination due to Seismic Events		Liquefaction-induced hazard potential is moderate during all seismic events. Seismic slope failure potential is low at 100-year, moderate at 500-year, high at 2,500-year event. Potential risk for a flow slide is low.									Liquefaction-induced hazard potential is low to moderate during all seismic events. Seismic slope failure potential is low at 100-year, moderate at 500-year, high at 2,500-year event. Potential risk for a flow slide is low.					Liquefaction-induced hazard potential is low during all seismic events. No re-exposure of remaining contamination potential for Alternative 4C.	
		Adequacy & Reliability of Controls	Institutional Controls	sitewide ICs	No ICs implemented.	Institutional controls are required for all remedial alternatives to manage residual seafood consumption risks except Alternative 2A4c and 4C.														
				Future use restrictions (based on area remediated by capping)		Moderate 10.3 acres	Moderate 10.3 acres	Moderate to high 18 acres	Moderate 10.3 acres	Moderate to high 18 acres	High 30	High 40	Moderate 10.3 acres	Low 5.4 acres	Low 5.4 acres	Low 6.3 acres	Very low 1.3 acres	No cap area, no future use restrictions	No cap area, no future use restrictions	No cap area, no future use restrictions
			Long-term Operation and Maintenance Monitoring (based on area remediated by capping and ENR)			Moderate 18 acres	Moderate to high 30	Moderate to high 30	High 40	Moderate 18 acres	Moderate to high 30	High 40	High 40	Moderate to high 30	Moderate to high 30	Moderate to high 30	Moderate to high 30	Moderate 18	Moderate to high 30	No long-term O&M required
	Summary of Short-Term Effectiveness				No short-term impacts but contamination remains above protective levels.	Low short-term impacts during construction.	Low short-term impacts during construction.	Low short-term impacts during construction.	Low short-term impacts during construction.	Low short-term impacts during construction.	Low to moderate short-term impacts during construction.	Low to moderate short-term impacts during construction.	Moderate short-term impacts during construction.	Moderate short-term impacts during construction.	Moderate short-term impacts during construction.	Moderateshort-term impacts during construction.	Moderateshort-term impacts during construction.	High short-term impacts during construction and long time to achieve RAOs.	High short-term impacts during construction and longer time to achieve RAOs.	High short-term impacts during construction and longest time to achieve RAOs.
	Summary of Overall Protection of Human Health and the Environment				Does not provide adequate overall protection to human health and the environment.	Alternatives 2, 3, and 4 provide adequate overall protection to human health and the environment. All alternatives can be implemented in a manner that protects workers, the community, and the environment. Alternatives with longer construction periods have proportionately greater short-term impacts. Alternatives that dredge or cap a larger surface area have a lower potential for subsurface contamination to be re-exposed by mechanical disturbances (e.g., scour). Alternatives with caps have higher potential of subsurface contamination re-exposure during a seismic event. Re-exposure of subsurface contaminated sediment is likely to be localized and have limited effect on sitewide averages.														
Comply With or Waive ARARs	Compliance with ARARs	Water Quality Standards			Not expected to comply.	No active remedial measures are feasible or anticipated for the water column although water quality improvements are anticipated from sediment remediation and source control. It is not anticipated that any alternative will comply with all federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain. Similar long-term water quality improvements are expected for all alternatives.														
		Sediment Management Standards			Not expected to comply.	Alternatives 2, 3, and 4 are predicted to achieve the SQS immediately following implementation.														
		MTCA		Human Health Seafood Consumption	Not expected to comply.	Alternatives 2, 3, and 4 require engineering and institutional controls to comply with MTCA because the MTCA requirement to achieve natural background is generally not achievable. Only Alternatives 2A4c and 4C would achieve PRGs at completion of construction.														
				Human Health Direct Contact	Not expected to comply.	All alternatives achieve the cumulative direct contact goal of $<1 \times 10^{-5}$.														
	Summary of ARARs				Not expected to comply.	All alternatives comply.														
Achieve Threshold Requirements					No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 13-1. Comparative Evaluation of Remedial Alternatives

Evaluation Criteria				Remedial Alternative															
				1	2A1	2A2a	2A2b	2A3	2A4a	2A4b	2A4c	2B	3A1	3A2	3B	3C	4A	4B	4C
Long-Term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated Sediment Remaining in the Subsurface)	Total dredge area (acres)		n/a	0	0	0	0	0	0	0	10.3	10.3	18	4	10.3	18	30	40
		Total cap and partial dredge/cap area (acres)		n/a	10.3	10.3	18	10.3	18	30	40	10.3	5.4	5.4	6.3	1.3	0	0	0
		Total ENR area (acres)		n/a	7.7	19.7	12	29.7	0	0	0	29.7	19.7	12	19.7	18.4	0	0	0
		Performance dredge volume (x1,000 cy)		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.8	55.5	123.0	90.0	148.5	342.0	802.5	1,214.3
		Contaminant mass removed (metric tons)		0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.1	38.3	50.6	59.7	91.0	136.9	181.2	194.9
		Number of cores remaining after construction with >CSL or SQS under caps (<3 ft)		28	19	19	24	19	24	26	28	19	6	6	8	3	0	0	0
		Number of cores remaining after construction with >CSL or SQS under ENR and no action areas (<3 ft)		28	9	9	4	9	4	2	0	9	9	5	9	11	4	2	0
		Summary		Largest amount of subsurface contamination and greatest potential for re-exposure.	Low to moderate potential for re-exposure.	Low to moderate potential for re-exposure.	Low potential for re-exposure.	Low to moderate potential for re-exposure.	Low potential for re-exposure.	Low potential for re-exposure.	Very low potential for re-exposure.	Low to moderate potential for re-exposure.	Low to moderate potential for re-exposure.	Low potential for re-exposure.	Low to moderate potential for re-exposure.	Low to moderate potential for re-exposure.	Very low potential for re-exposure.	Very low potential for re-exposure.	No potential for re-exposure.
	Adequacy & Reliability of Controls[6/]	Long-term Operation and Maintenance Monitoring (based on area remediated by capping and ENR)		No monitoring	Same relative rankings as for monitoring and maintenance (see above).														
		Magnitude and Duration of Institutional Controls	Seafood consumption advisories, public outreach, and education	No outreach or education	Seafood consumption advisories, public outreach, and education are required for the Lockheed West site and are of similar magnitude and duration regardless of alternative except Alternative 4C.														
			Future use restrictions (based on area remediated by capping)	No institutional controls	Same relative rankings as for future use restrictions (see above).														
			Summary	No institutional controls	The need for monitoring and maintenance is higher for containment-focus and removal-focus alternatives and less for complete removal alternatives. Seafood consumption advisories, public outreach, and education are required and of similar magnitude/duration regardless of alternative except for complete removal alternatives. Monitoring of waterway permitting and use activities is highest for containment-focus alternatives. Complete removal alternatives require no monitoring and notification activity because no subsurface contaminated sediment remains in place.													
Reduction of Toxicity, Mobility, or Volume through Treatment	Summary			No treatment	No treatment														
Short-term Effectiveness	Protection of Workers, Community, and Environment during Construction[7/]	Period of community exposure, worker exposure and ecological disturbance (years of construction)		n/a	1	1	1	1	1	1	1	1	1	1	1	2	3	6	9
		Transportation – (truck miles/train miles)		0	6,000/2,000	6,000/2,000	6,000/2,000	6,000/2,000	6,000/2,000	6,000/2,000	6,000/2,000	38,000/11,000	40,000/12,000	80,000/23,000	60,000/18,000	96,000/28,000	212,000/61,000	488,000/141,000	735,000/212,000
		Ecological – Habitat area above -10 ft MLLW disturbed (dredging/partial dredge and cap/capping)		0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Fuel consumption (1,000 gal)		0	94	113	143	128	124	189	244	220	190	307	255	339	653	1,483	2,224
		Greenhouse gas emissions (CO_2; long tons)		0	1,075	1,289	1,634	1,468	1,419	2,170	2,796	2,573	2,230	3,636	3,011	4,030	7,823	17,800	26,712
		Particulate matter emissions (PM_{10}; long tons)		0	1.5	1.7	2.0	1.9	1.8	2.6	3.2	11.9	12.2	25.3	19.0	30.1	67.3	156.9	237.0
		Depleted natural resources (sand/gravel for in-water placement; cy)		0	89,200	108,500	139,600	124,700	120,200	187,900	244,400	124,700	86,700	83,600	90,700	70,100	40,200	54,800	66,900
		Landfill capacity used (1.2 × dredge vol; cy)		0	11,940	11,940	11,940	11,940	11,940	11,940	11,940	74,100	78,540	159,540	119,940	190,140	422,340	974,940	1,469,100
	Summary of Short-Term Effectiveness			No short-term impacts but contamination remains above protective levels.	Low short-term impacts during construction.	Low short-term impacts during construction.	Low short-term impacts during construction.	Low short-term impacts during construction.	Low short-term impacts during construction.	Moderate short-term impacts during construction.	Moderate short-term impacts during construction.	Moderate short-term impacts during construction.	Moderate short-term impacts during construction.	Moderate short-term impacts during construction.	Moderate short-term impacts during construction.	Moderate short-term impacts during construction.	High short-term impacts during construction and long time to achieve RAOs.	High short-term impacts during construction and longer time to achieve RAOs.	High short-term impacts during construction and longest time to achieve RAOs.
Implementability	Technical and Administrative Feasibility	Total actively remediated area (acres)		0	20	32	32	40	20	32	40	40	32	32	32	32	20	32	40
		Total removal volume (x1,000 cy)[8/]		0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	61.8	65.5	133.0	100.0	158.5	352.0	812.5	1,224.3
		Technical and administrative implementability during construction		No construction period. No potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Moderate potential for technical/ administrative difficulties and schedule delays.	Short construction period. Moderate potential for technical/ administrative difficulties and schedule delays.	Short construction period. Moderate potential for technical/ administrative difficulties and schedule delays.	Short construction period. Moderate potential for technical/ administrative difficulties and schedule delays.	Moderate construction period. Moderate potential for technical/ administrative difficulties and schedule delays.	Moderate construction period. Moderate potential for technical/ administrative difficulties and schedule delays.	Long construction period. High potential for technical/ administrative difficulties and schedule delays.	Long construction period. High potential for technical/ administrative difficulties and schedule delays.
		Technical and administrative implementability of ICs		Moderate Administration of current ICs (e.g. regional seafood advisory).	Low to moderate Monitoring and notification of waterway users, easements, and permits are required for cap areas; in addition to seafood consumption advisory, public outreach and education, site registry for the cap areas.											Moderate Seafood consumption advisory, public outreach and education.			Moderate to high No site-specific IC required.
	Summary			High	Moderate to High	Moderate to High	Moderate to High	Moderate to High	Moderate to High	Moderate to High	Moderate to High	Moderate	Moderate	Moderate	Moderate	Moderate	Low to Moderate	Low to Moderate	Low to Moderate
Costs	Total (MM$)			0	17.0	18.7	25.0	20.2	22.4	34.1	43.8	33.3	28.9	47.5	37.5	47.0	92.3	204.0	302.8

Notes:

1/ Average performance for all COCs is reported. See Table 12-2 and Table 12-3 for performance toward reaching RAO1 PRGs for individual risk-driver COCs.

2/ Cumulative risks lower than 1×10^{-5} are within the acceptable CERCLA risk range.

3/ For Alternative 2A1 and 2A4a, PRG for arsenic not achieved (see Table 12-3).

4/ PRG for total PCBs not achieved; average of COC HQ < 1 (see Table 12-3).

5/ Remaining cores grouped by those located under caps, ENR, dredged areas <3ft. At least one parameter was above the CSL in one sample interval for the depth or at least one parameter is above the SQS and no parameters are above the CSL in one sample interval for the depth.
Remaining cores under ENR and dredged areas pose slighly higher risk than the ones under caps. Convential caps (min. 3 ft thickness) designed for complete isolation.

6/ This analysis evaluates the reliability of controls after construction is completed and RAOs are achieved. Various controls will also be required during construction.

7/ Refer to Appendix G for details of short-term effectiveness metrics.

8/ Volume includes Performance dredge volume and Shoreline/Shipway removal volumes.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; CSL = cleanup screening level; cy = cubic yards; ENR = enhanced natural recovery; HQ = hazard quotient; IC = institutional control; MLLW = mean low lower water; MM = million; n/a = not applicable; PCB = polychlorinated biphenyls; RAO = remedial action objective; SQS = sediment quality standard.

Table 13-2. Relative Ranking of Remedial Alternatives

Evaluation Criteria (Ranking Weight)			Basis	Scale [1/]		Alternative 1	Alternative 2								Alternative 3				Alternative 4		
CERCLA Criteria		FS Analysis Factors		0	10	1	2A1	2A2a	2A2b	2A3	2A4a	2A4b	2A4c	2B	3A1	3A2	3B	3C	4A	4B	4C
Threshold	**1. Overall Protection of Human Health and Environment (0%)**	• How alternative provides human health and environmental protection	RAO1 [3/]	baseline	achievement of PRGs	**1.7**	**8.9**	**9.3**	**9.7**	**9.4**	**9.3**	**9.9**	**10.0**	**9.6**	**9.5**	**9.4**	**9.3**	**9.4**	**9.5**	**9.7**	**10.0**
						17%	89%	93%	97%	94%	93%	99%	100%	96%	95%	94%	93%	94%	95%	97%	100%
			RAO2 [4/, 5/]	baseline	achievement of PRGs	**0**	**5**	**10**	**10**	**10**	**5**	**10**	**10**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**
						no	partial	yes	yes	yes	partial	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
			RAO3	SMS exccedances	No SMS	**0**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**
						no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
			RAO4 [6/]	baseline	achievement of PRGs	**0**	**7**	**10**	**10**	**10**	**10**	**10**	**10**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**
						no	partial	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
					Average [2/]	**0.4**	**7.7**	**9.8**	**9.9**	**9.8**	**8.6**	**10.0**	**10.0**	**9.9**	**9.9**	**9.9**	**9.8**	**9.8**	**9.9**	**9.9**	**10.0**
	2. Compliance with ARARs (0%)	• Compliance with chemical specific, location specific, and action specific ARARs	RAO3	Baseline surface locations > SMS (54)	0 surface locations > SMS	**0**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**
						54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Average [2/]	**0.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**
Primary Balancing	**3. Long-term Effectiveness and Permanence (50%)**	• Magnitude of residual risks	Residual risk in the surface sediments	baseline	Achievement of RAO 1 PRGs	**1.7**	**8.9**	**9.3**	**9.7**	**9.4**	**9.3**	**9.9**	**10.0**	**9.6**	**9.5**	**9.4**	**9.3**	**9.4**	**9.5**	**9.7**	**10.0**
		• Magnitude of residual risk from reexposure of subsurface cores	Number of cores with SMS exceedances	baseline	0	**0.0**	**6.6**	**6.9**	**7.9**	**7.1**	**7.7**	**8.4**	**9.0**	**7.1**	**7.3**	**8.3**	**6.8**	**6.9**	**8.6**	**9.3**	**10.0**
			# cores < 3 ft no cap	Weighting: 1.0		28	4	2	2	0	4	2	0	0	2	2	2	2	4	2	0
			# cores < 3 ft ENR	Weighting: 0.7		0	5	7	2	9	0	0	0	9	7	3	9	9	0	0	0
			# cores < 3 ft under cap	Weighting: 0.1		0	19	19	24	19	24	26	28	19	6	6	8	3	0	0	0
		• Mass of contaminants removed	Relative to the mass of risk-driver contaminants	0 MT	200 MT	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.2**	**1.9**	**2.5**	**3.0**	**4.6**	**6.8**	**9.1**	**9.7**
						0	0	0	0	0	0	0	0	24	38	51	60	91	137	181	195
		• Re-exposure risk due to seismic events	Relative to area of dredging to non dredging area and the liquefaction-induced hazard potential	no hazard	high hazard	**0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**5.5**	**6.7**	**4.6**	**5.5**	**6.7**	**8.5**	**10.0**
				10	0																
		• Reliability of technology	Area actively remediated	0	40 acres	**0.0**	**4.5**	**7.5**	**7.5**	**10.0**	**4.5**	**7.5**	**10.0**	**10.0**	**7.5**	**7.5**	**7.5**	**7.5**	**4.5**	**7.5**	**10.0**
						0	18	30	30	40	18	30	40	40	30	30	30	30	18	30	40
			Relative factor of technology and area of	0 eq acres [7/]	40 eq acres	**0.0**	**3.0**	**4.5**	**5.1**	**5.8**	**3.6**	**6.0**	**8.0**	**5.8**	**5.9**	**6.6**	**4.6**	**4.9**	**4.1**	**6.8**	**9.0**
			Acres of Dredge	Weighting: 9		0	0	0	0	0	0	0	0	0	10.3	18	4	10.3	18	30	40
			Acres of Cap	Weighting: 8		0	10.3	10.3	18	10.3	18	30	40	10.3	5.4	5.4	6.3	1.3	0	0	0
			Acres of ENR	Weighting: 5		0	7.7	19.7	12	29.7	0	0	0	29.7	19.7	12	19.7	18.4	0	0	0
		• Monitoring considerations	Relative to area of cap and ENR	40 acres	0 acres	**10**	**5.5**	**2.5**	**2.5**	**0.0**	**5.5**	**2.5**	**0.0**	**0.0**	**2.5**	**2.5**	**2.5**	**2.5**	**5.5**	**2.5**	**10.0**
						0	18	30	30	40	18	30	40	40	30	30	30	30	18	30	0
		• Adequacy and reliability of controls	Institutional Controls required long term	Cap+ (3), none Cap (7)	none	**0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**7.0**	**7.0**	**10.0**
						NA	Cap	Cap	Cap	Cap	Cap	Cap	Cap	Cap	Cap	Cap	Cap	Cap	none Cap	none Cap	none
			Future use limitiations (relative to acres capped)	40 acres	0 acres	**10**	**7.4**	**7.4**	**5.5**	**7.4**	**5.5**	**2.5**	**0**	**7.4**	**8.7**	**8.7**	**8.4**	**9.7**	**10.0**	**10.0**	**10.0**
						0	10.3	10.3	18	10.3	18	30	40	10.3	5.4	5.4	6.3	1.3	0	0	0
			Port Future Development limitations	yes	none	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**	**0.0**	**8.5**	**9.7**	**10.0**	**10.0**	**10.0**
						yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	small	minor	none	none	none
			Acres of ENR and no action taken	38 acres	0 acres	**10**	**2.2**	**2.2**	**4.2**	**2.2**	**4.2**	**7.4**	**10**	**2.2**	**3.6**	**5.6**	**2.2**	**2.5**	**6.8**	**7.9**	**10.0**
						0	29.7	29.7	22	29.7	22	10	0	30	24	17	30	28	12	8	0
					Average [2/]	**2.9**	**4.1**	**4.3**	**4.5**	**4.4**	**4.3**	**4.6**	**4.9**	**4.6**	**5.0**	**5.5**	**5.5**	**6.0**	**7.2**	**8.0**	**9.9**
	4. Reductions in Toxicity, Mobility, and Volume Through Treatment (n/a)	n/a	n/a	n/a	n/a	No Treatment															
	5. Short-term Effectiveness (25%)	• Protection of community during remedial actions	Relative to volume material removed, handled and transported	1.5 MM cy	0 cy	**10**	**9.5**	**9.4**	**9.2**	**9.3**	**9.3**	**8.9**	**8.5**	**8.9**	**9.1**	**8.8**	**9.0**	**8.7**	**7.7**	**4.7**	**1.9**
						0	70.7	90	121.1	106.2	101.7	169.4	225.9	158	134	173	157	188	342	802.5	1,214
		• Protection of workers during remedial actions • Environmental impacts	Relative to volume material removed, handled and transported	1.5 MM cy	0 cy	**10.0**	**9.5**	**9.4**	**9.2**	**9.3**	**9.3**	**8.9**	**8.5**	**8.9**	**9.1**	**8.8**	**9.0**	**8.7**	**7.7**	**4.7**	**1.9**
						0	70.7	90	121.1	106.2	101.7	169.4	225.9	158	134	173	157	188	342	802.5	1,214
		• Time until remedial actions are completed	Time to complete	9 yrs	0 yr	**10.0**	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**	**7.8**	**6.7**	**3.3**	**0.0**
						0	1	1	1	1	1	1	1	1	1	1	1	2	3	6	9
					Average [2/]	**10.0**	**9.3**	**9.2**	**9.1**	**9.2**	**9.2**	**8.9**	**8.6**	**8.9**	**9.0**	**8.9**	**8.9**	**8.4**	**7.4**	**4.2**	**1.3**

Table 13-2. Relative Ranking of Remedial Alternatives

Evaluation Criteria (Ranking Weight)			Basis	Scale [1/]		Alternative 1	Alternative 2								Alternative 3				Alternative 4		
CERCLA Criteria		FS Analysis Factors		0	10	1	2A1	2A2a	2A2b	2A3	2A4a	2A4b	2A4c	2B	3A1	3A2	3B	3C	4A	4B	4C
	6. Implementability (25%)	• Ability to construct and operate technology • Reliability of technology • Ease of undertaking additional remedial action if necessary • Monitoring considerations • Administrative feasibility • Availability of services and materials • Implementability of ICs • Time until remedial actions are completed	Relative factor of technology and area of implementation	40 eq acres [7/]	0 eq acres	**10.0**	**7.7**	**6.5**	**6.1**	**5.5**	**7.3**	**5.5**	**4.0**	**5.5**	**4.6**	**3.5**	**6.1**	**5.4**	**5.5**	**2.5**	**0.0**
			Acres of Dredging	Weighting: 10		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.3	18.0	4.0	10.3	18.0	30.0	40.0
			Acres of Capping	Weighting: 6		0.0	10.3	10.3	18.0	10.3	18.0	30.0	40.0	10.3	5.4	5.4	6.3	1.3	0.0	0.0	0.0
			Acres of ENR	Weighting: 4		0.0	7.7	19.7	12.0	29.7	0.0	0.0	0.0	29.7	19.7	12.0	19.7	18.4	0.0	0.0	0.0
			Relative to volume material removed, handled and transported	1.5 MM cy	0 cy	**10** 0	**9.5** 70.7	**9.4** 90	**9.2** 121.1	**9.3** 106.2	**9.3** 101.7	**8.9** 169.4	**8.5** 225.9	**8.9** 158	**9.1** 134	**8.8** 173	**9.0** 157	**8.7** 188	**7.7** 342	**4.7** 802.5	**1.9** 1,214
			Time to complete [8/]	9 yrs	0 yr	**0** >10	**8.9** 1	**8.9** 1	**8.9** 1	**8.9** 1	**8.9** 1	**8.9** 1	**8.9** 1	**8.9** 1	**8.9** 1	**8.9** 1	**8.9** 1	**7.8** 2	**6.7** 3	**3.3** 6	**0.0** 9
					Average [2/]	**6.7**	**8.7**	**8.3**	**8.1**	**7.9**	**8.5**	**7.8**	**7.1**	**7.8**	**7.5**	**7.1**	**8.0**	**7.3**	**6.6**	**3.5**	**0.6**
					Average Ranking	**6.5**	**7.4**	**7.3**	**7.2**	**7.2**	**7.3**	**7.1**	**6.9**	**7.1**	**7.2**	**7.2**	**7.5**	**7.2**	**7.1**	**5.2**	**3.9**
					Weighted Ranking	**5.6**	**6.6**	**6.5**	**6.5**	**6.5**	**6.6**	**6.5**	**6.4**	**6.5**	**6.7**	**6.8**	**7.0**	**6.9**	**7.1**	**5.9**	**5.4**
	7. Cost	• Total direct/indirect costs including all labor, equipment, and material costs • O&M costs, monitoring	Total cost ($ MM)	n/a	n/a	0	17.0	18.7	25.0	20.2	22.4	34.1	43.8	33.3	28.9	47.5	37.5	47.0	92.3	204.0	302.8

Notes:

1/ A score of 0 represents a low ranking for the given metric. A score of 10 represents a high ranking for a given metric. Scores of 0 or 10 do not necessarily represent the results for the lowest or highest alternatives, but represent the high and low relative scores for the shown scale. The alternatives are scored on a linear scale between the high and low points.

2/ Criteria rankings for each alternative are the average score for each of the metrics listed under the criteria.

3/ Average performance for all COCs is reported. See Table 12-2 and Table 12-3 for performance toward reaching RAO1 PRGs for individual risk-driver COCs.

4/ Cumulative risks lower than 1 × 10-5 are within the acceptable CERCLA risk range. All sitewide areas are below the 90th percentile (i.e., 11 mg/kg-dw) but above the 95 UCL (i.e., 7 mg/kg-dw) of the natural background dataset for arsenic (the arsenic PRG is natural background). All other risk-driver COCs are below their specific PRGs.

5/ For Alternative 2A1, PRG for arsenic not achieved (see Table 12-3).

6/ PRG for total PCBs not achieved; average of COC HQ < 1 (see Table 12-3).

7/ Rankings based on the area over which the technology is applied multiplied by the technology factor divided by the acreage of the study area

8/ For Implementability, because Alternative 1 does not achieve the RAOs the ranking for time to complete is given a 0.

ARAR = applicable or relevant and appropriate requirement; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; cy = cubic yards; ENR = enhanced natural recovery; FS = Feasibility Study; IC = institutional control;MM = million; MT = metric ton; n/a = not applicable; PCB = polychlorinated biphenyls; PRGs = Preliminary Remedial Goals; RAO = remedial action objective; SMS = sediment management standards

Figure 13-1. Comparative Analysis - Actively Remediated Area and Dredge Volume

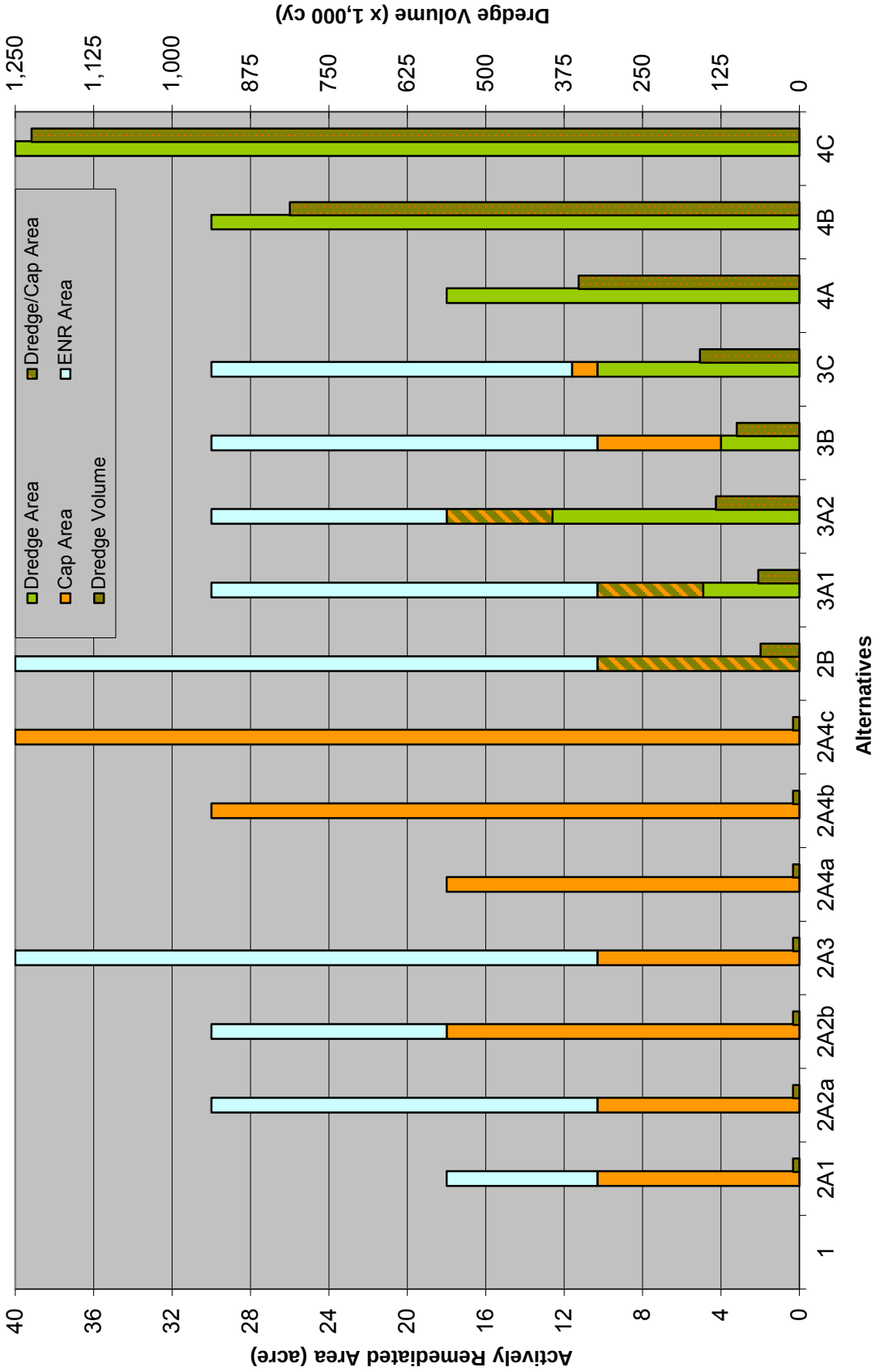


Figure 13-2. Comparative Analysis - Average Relative Performance towards Reaching RAO 1 PRGs from Mean Baseline

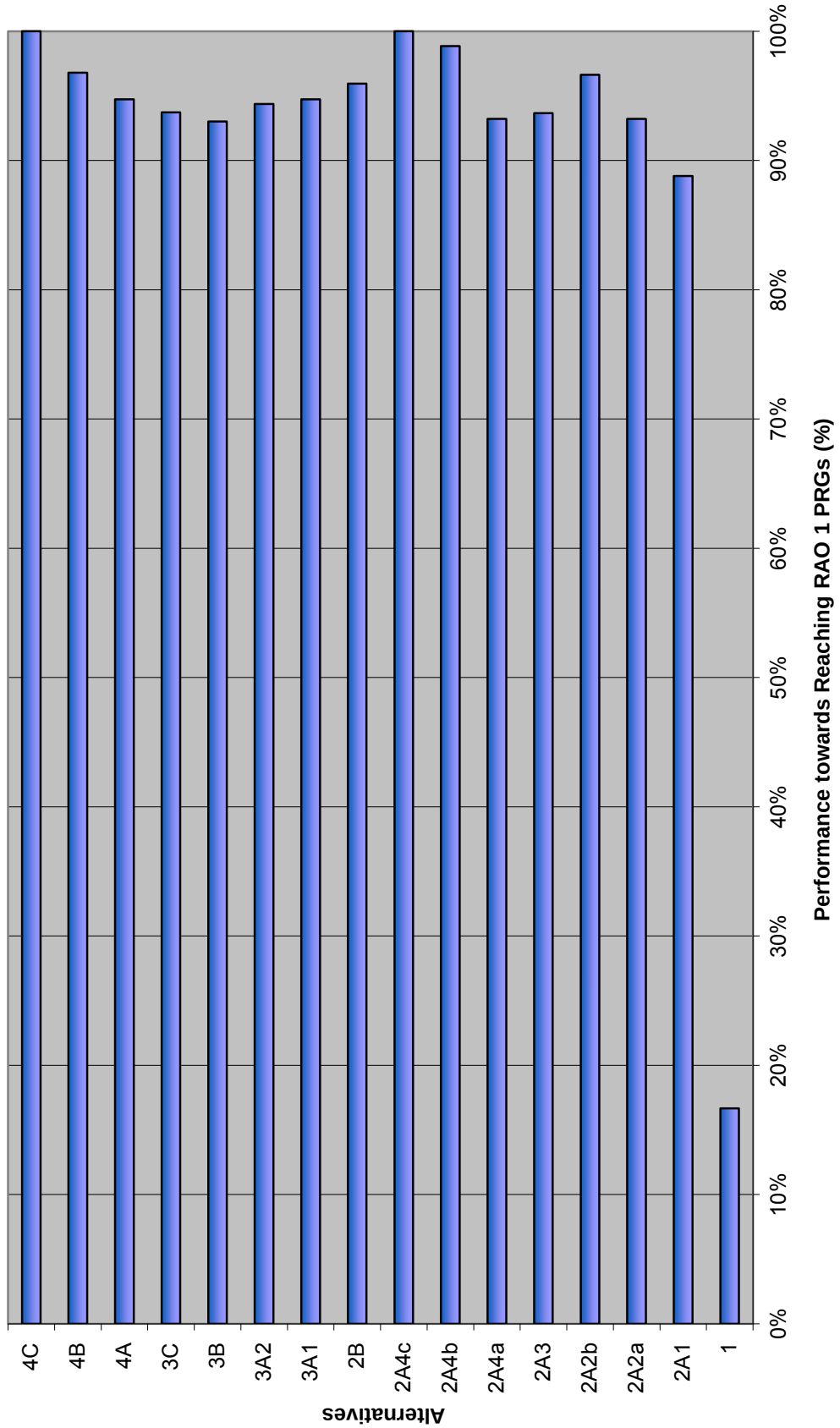


Figure 13-3a. Comparative Analysis - Contaminant Mass Removal of COCs (Cu, Pb, As) to Dredge Volume

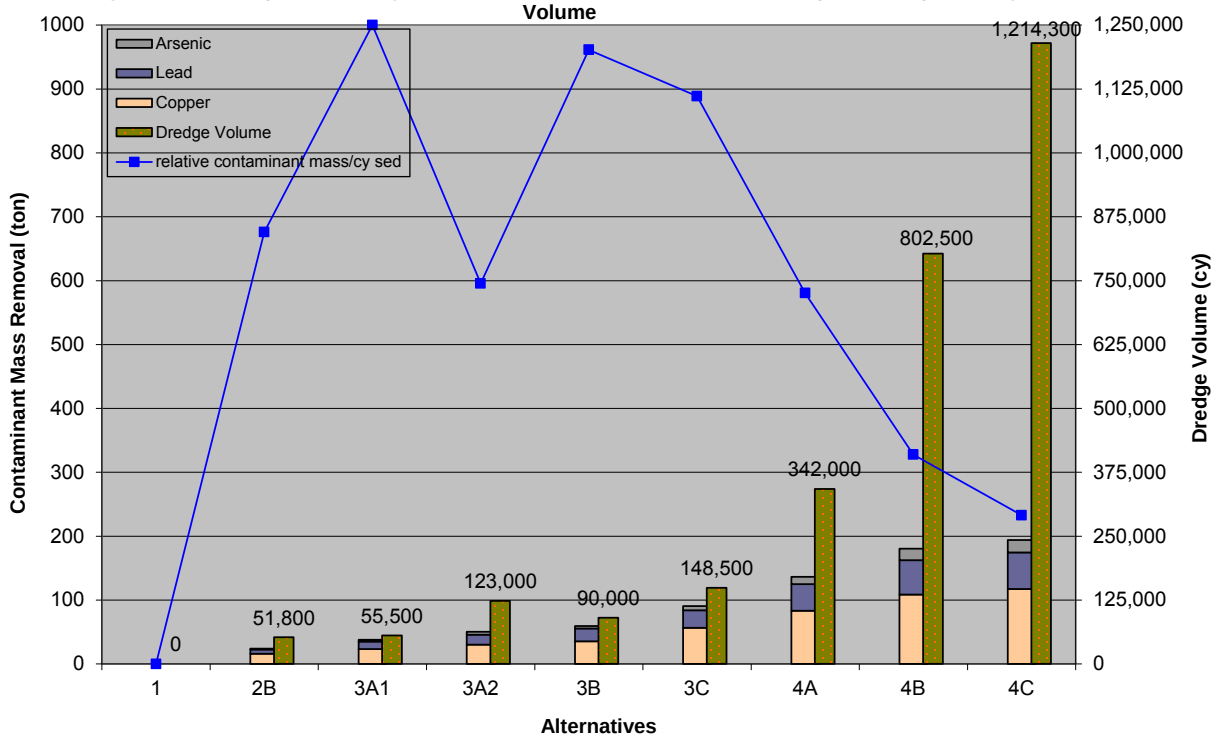
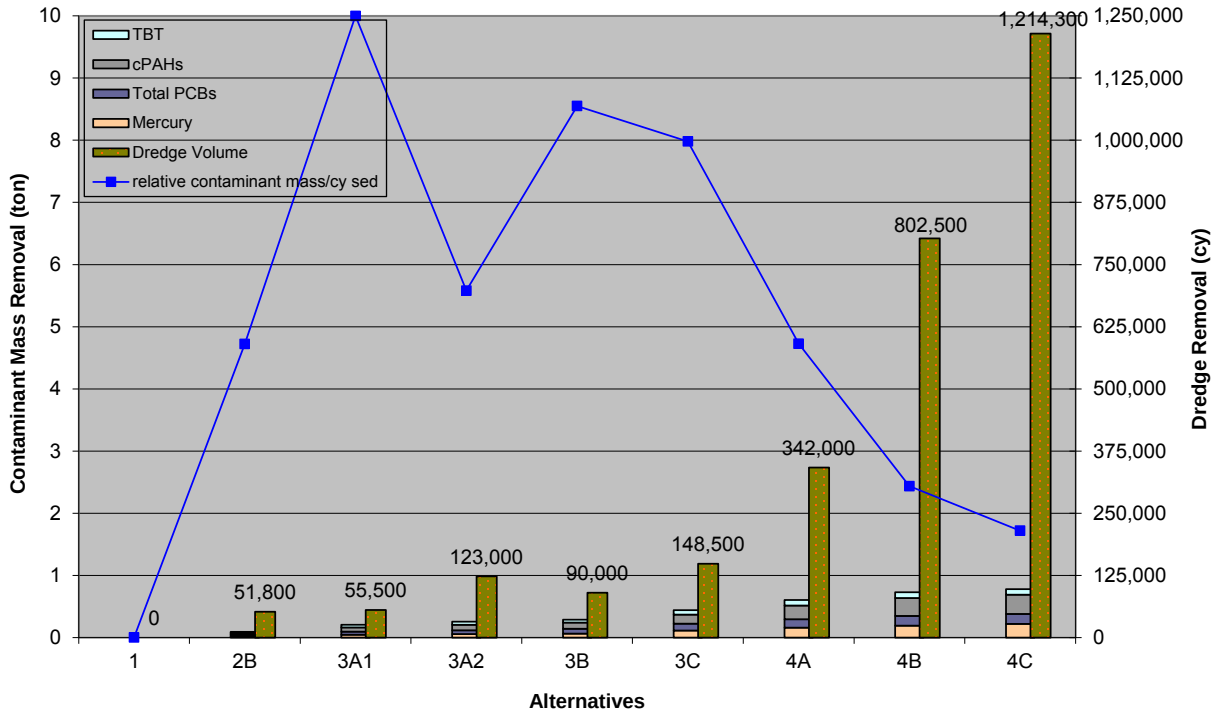


Figure 13- 3b. Comparative Analysis - Contaminant Mass Removal of COCs (Hg, PCBs, cPAHs, TBT) to Dredge Volume



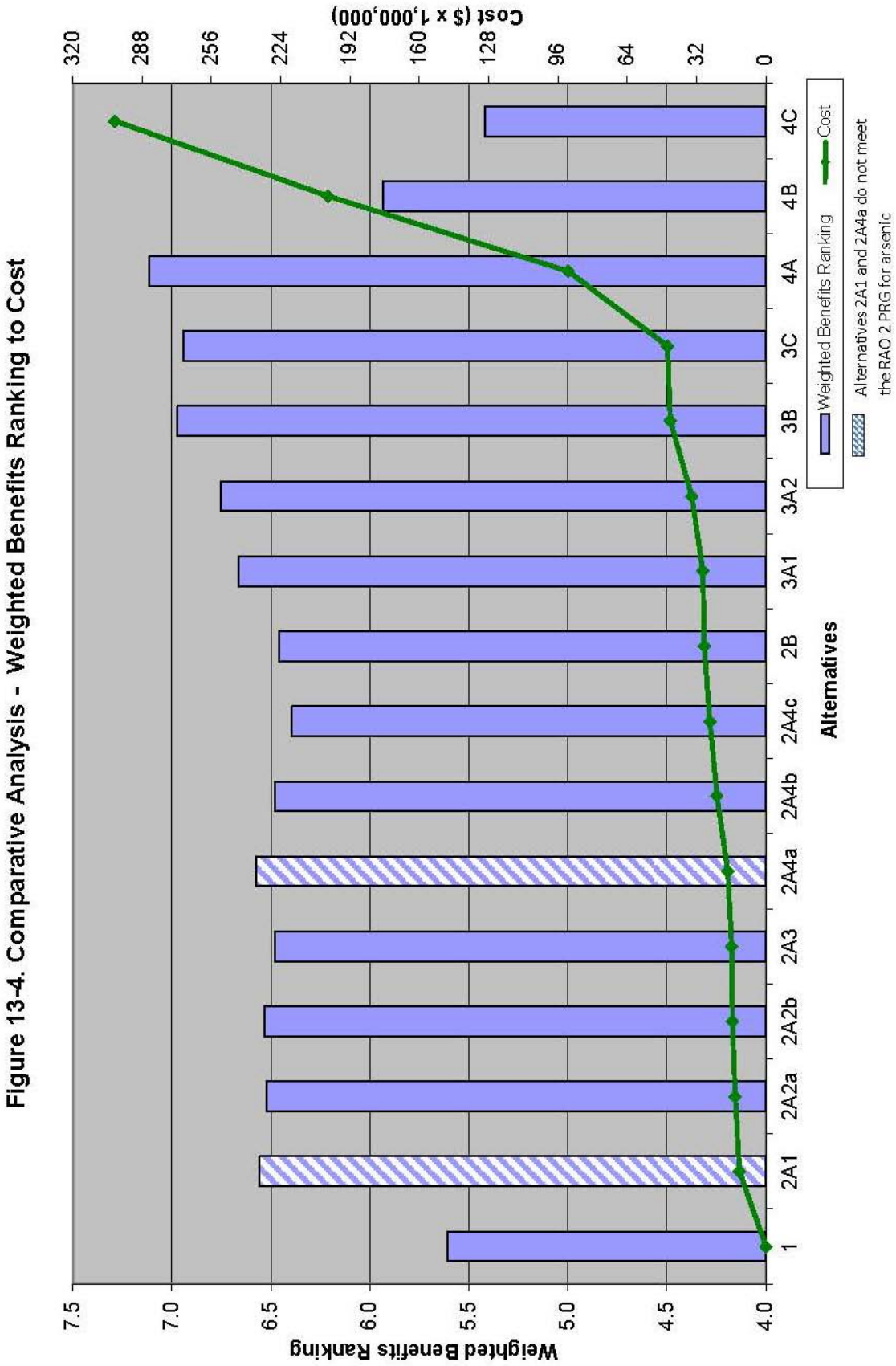


Figure 13-4. Comparative Analysis - Weighted Benefits Ranking to Cost
Weighted Benefits Ranking
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
Cost ($ x 1,000,000)
320
288
256
224
192
160
128
96
64
32
0
1
2A1
2A2a
2A2b
2A3
2A4a
2A4b
2A4c
2B
3A1
3A2
3B
3C
4A
4B
4C
Alternatives
Weighted Benefits Ranking
Cost
Alternatives 2A1 and 2A4a do not meet the RAO 2 PRG for arsenic

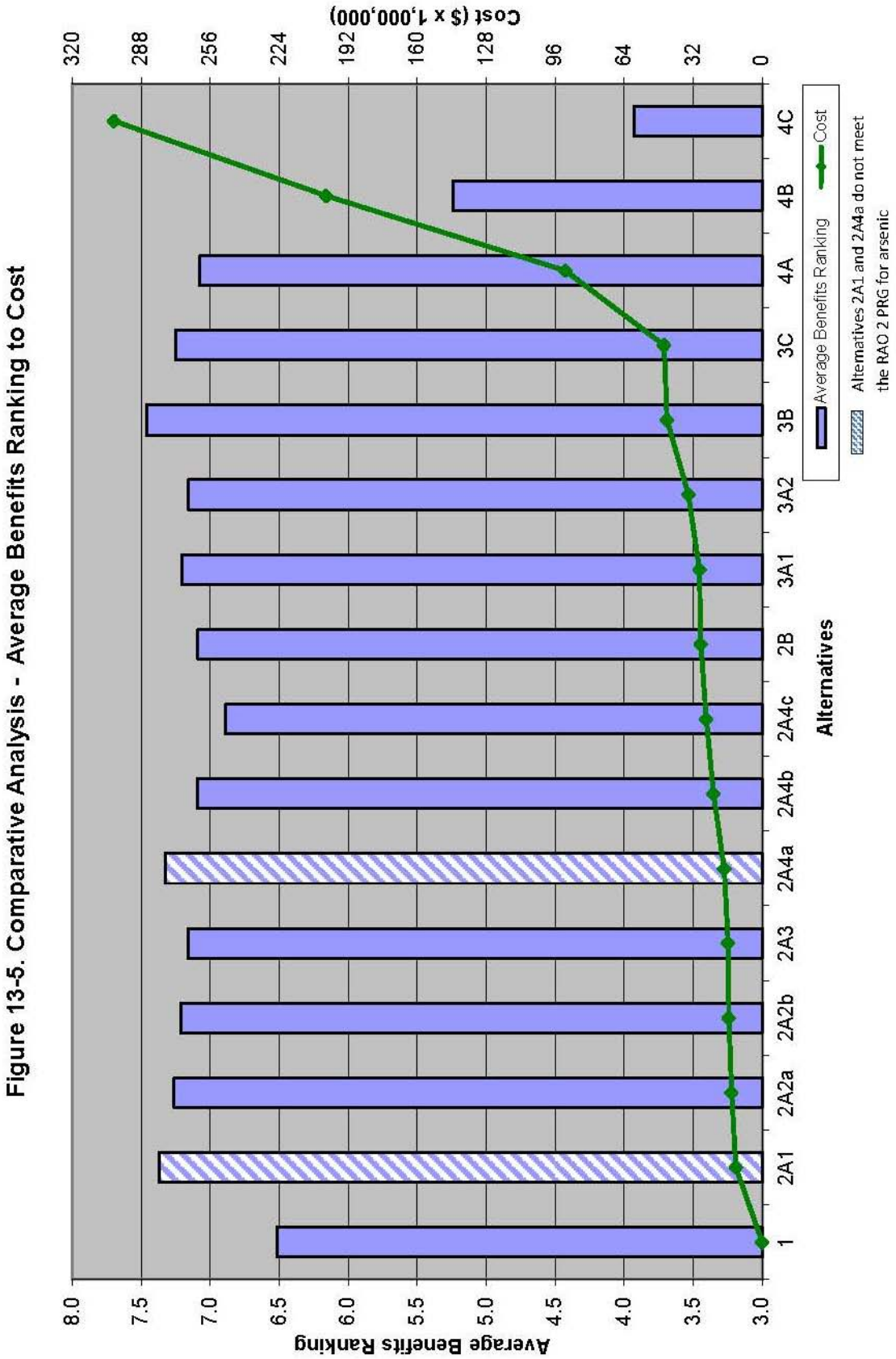


Figure 13-5. Comparative Analysis - Average Benefits Ranking to Cost
Average Benefits Ranking
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
Cost ($ x 1,000,000)
320
288
256
224
192
160
128
96
64
32
0
1
2A1
2A2a
2A2b
2A3
2A4a
2A4b
2A4c
2B
3A1
3A2
3B
3C
4A
4B
4C
Alternatives
Average Benefits Ranking
Cost
Alternatives 2A1 and 2A4a do not meet the RAO 2 PRG for arsenic

Figure 13-6. Comparative Analysis - Actively Remediated Area, Dredge Volume, Weighted Benefits to Cost

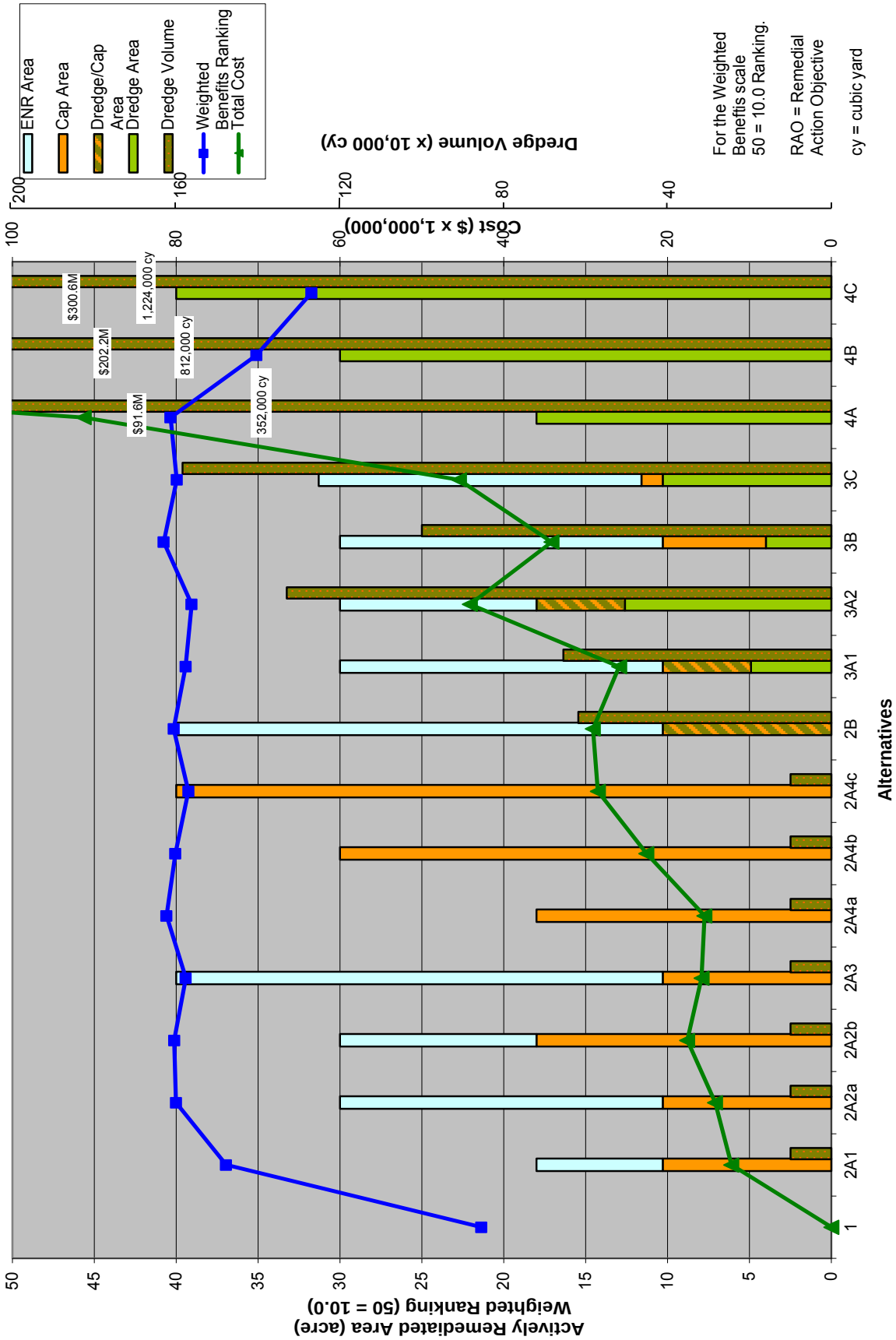
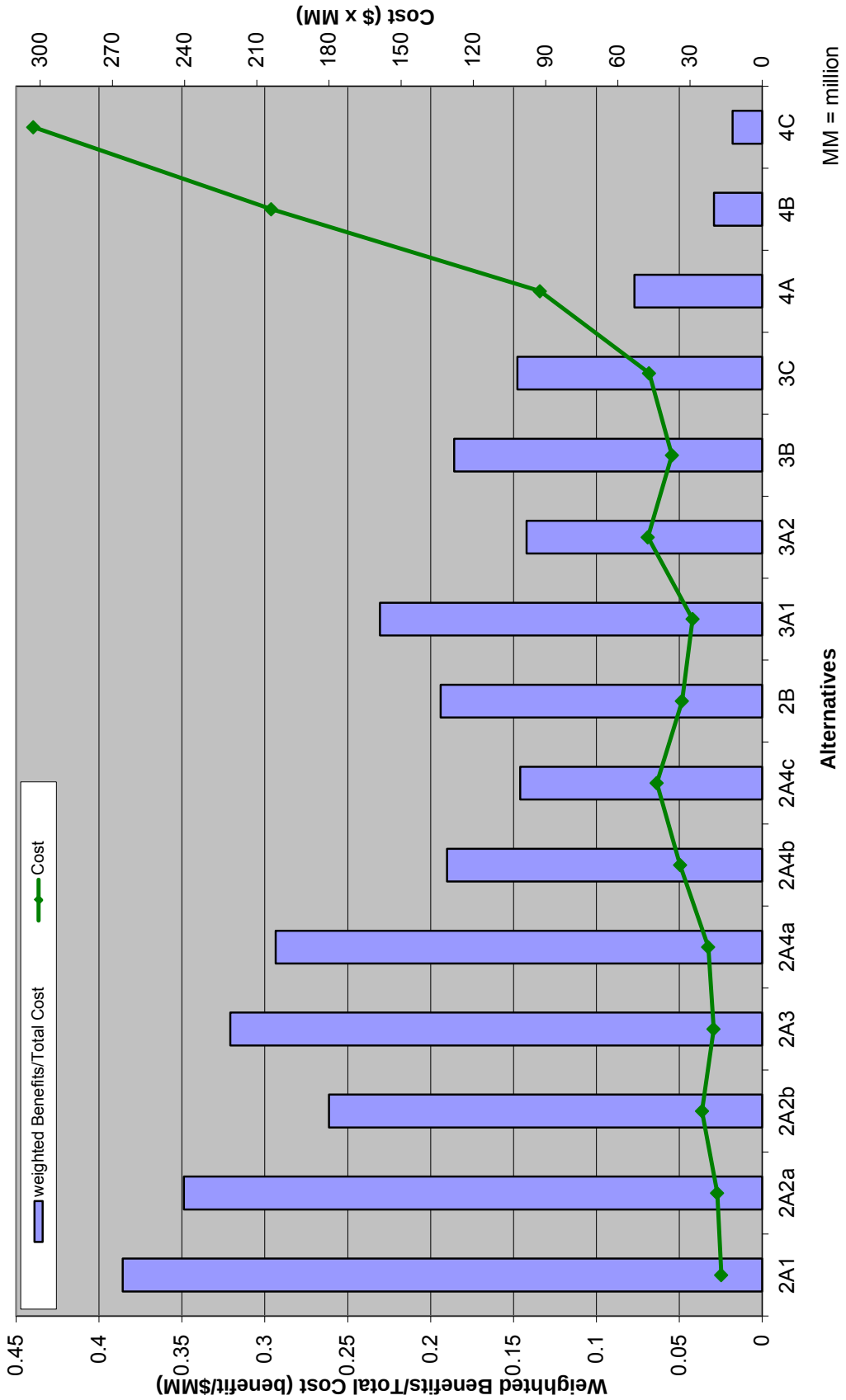


Figure 13-7. Remedial Alternatives Comparative Analysis - Weighted Benefits Ranking per Unit Cost



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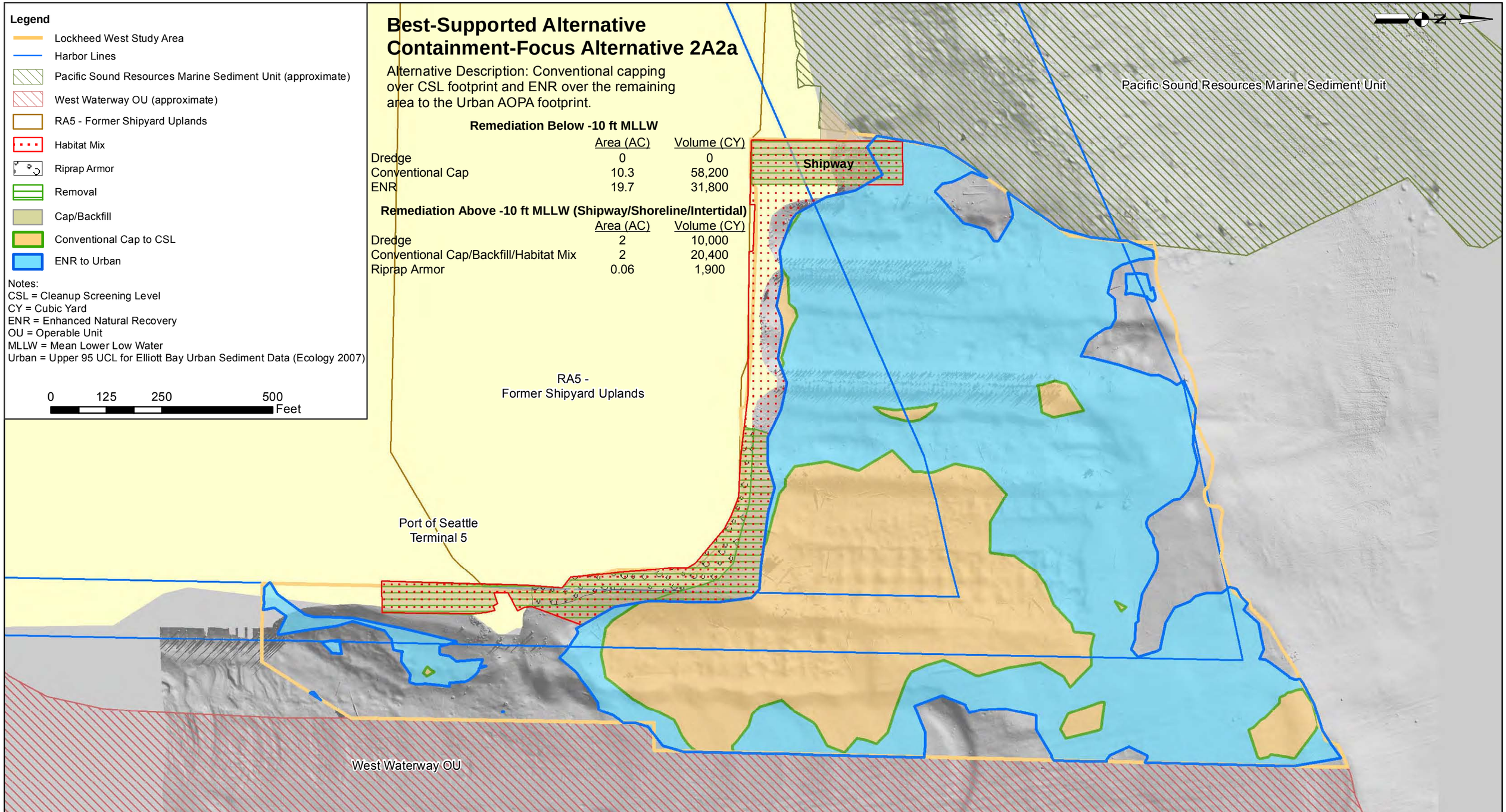

TETRA TECH

Lockheed West Seattle Superfund Site, Seattle, WA

Figure 13-8
Best-Supported Alternative
Alternative 2A2a

Z:\Pdrive\Projects_2006\Lockheed\maps\RIFS_Report\Fig_13-8.mxd

SECTION 14
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Glossary

A

Absorption – The incorporation of a substance in one physical state into another in a different physical state (absorption); e.g., the uptake of water, other fluids, or dissolved chemicals by a cell or an organism.

Adsorption – The process in which a substance adheres to the surface of a solid material.

Advection – The process of transport of matter by a mass of flowing fluid (e.g., a river).

Alluvium – Unconsolidated terrestrial sediment composed of sorted or unsorted sand, gravel, and clay that has been deposited by water.

Amalgamated – Referring to a mix of different elements.

Analyte – A compound or property that is to be determined and/or analyzed.

Anisotropy – Properties having different values depending on the direction of the measurement.

Anoxic – Term to describe an environment that is lacking oxygen.

Anthropogenic – An effect or object resulting from human activity; e.g., natural and human-made substances may be present in the environment as a result of human activities.

Applicable or Relevant and Appropriate Requirement (ARAR) – Any state or federal statute that pertains to protection of human life and the environment in addressing specific conditions or use of a particular cleanup technology at a Superfund site.

Aqueous – Something made from, with, or by water.

Aquifer – An underground geologic formation, or group of formations, containing water that can be readily transmitted and that is a source of groundwater for wells and springs.

Aroclor – Tradename of mixtures of PCBs. With the exception of Aroclor 1016, the last two numbers in the tradename designation correspond to the percentage of chlorine by weight.

Assessment Endpoint – In an ecological risk assessment, this is an expression of the environmental value to be protected; it includes both an ecological entity and specific attributes thereof. For example, salmon (i.e., the valued ecological entity) reproduction and population maintenance (i.e., attributes) is an assessment endpoint.

Attenuation – The process by which a chemical is reduced in concentration over time, through absorption, adsorption, degradation, dilution, and/or transformation. It can also be the decrease with distance of sight caused by attenuation of light by particulates.

Atterberg Limits – A basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic, and liquid. In each state the consistency and behavior of a soil is different and thus so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behavior. The Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays.

B

Background (Background Level) – 1) As defined by EPA, substances present in the environment that are not influenced by releases from a site and are usually described as naturally occurring or anthropogenic, where *naturally occurring* is defined as substances present in the environment in forms that have not been influenced by human activity, and *anthropogenic* is defined as natural and human-made substances present in the environment as a result of human activities but not specifically related to the CERCLA site in question. 2) In an exposure assessment, the concentration of a substance in a defined reference area, during a fixed period of time before, during, or after a data-gathering operation.

Bathymetry – The measurement of depths of water in rivers, lakes, oceans, and other water bodies. Also the information derived from such measurements. Bathymetry is expressed relative to a reference elevation or datum. The reference datum may differ for coasts and inland waterways such as the Columbia River and the Willamette River.

Bedload – Sediment particles resting on or near the channel bottom that are pushed or rolled along by the flow of water.

Benthic/Benthos – Relating to or characteristic of the bottom of an aquatic body or the organisms and plants that live there.

Bioaccumulation – The process by which an organism retains environmental chemicals in its body (possibly in a specific organ or tissue).

Bioassay Test – A test to determine the relative strength of a substance by comparing its effect on a test organism with that of a standard preparation.

Bioavailability – The degree of the tendency of a chemical to be absorbed by an organism into its bloodstream.

Biomagnification – Refers to the process whereby the concentrations of certain chemicals such as PCBs or dioxins increase in organism tissue with increase in trophic level (i.e., moving up the food chain). The substances become increasingly concentrated in tissues or internal organs as they move up the food chain.

Biota – The types of plant and animal life found in specific regions at specific times.

Biota-Sediment Accumulation Factor (BSAF) – The concentration of a chemical in tissue divided by a concentration in sediment.

Bioturbation – Mixing of sediment caused by benthic organism activities such as burrowing. Generally occurs in the top 10 centimeters of sediment.

C

Cap – A layer of clay, or other impermeable material, installed over the top of a closed landfill to prevent entry of rainwater and minimize leachate.

Carcinogen – Any substance that can cause or aggravate cancer.

Central Tendency – When referring to the exposure of organisms to a chemical, an estimate of the average exposure that may potentially be experienced by the population.

Contaminant(s) of Concern (COC) – Contaminants identified through the baseline risk assessment that potentially cause unacceptable adverse effects to human health and/or ecological receptors.

Contaminant(s) of Interest (COI) – Contaminants that have been detected at a site but have not been screened yet in the risk assessment process or have been screened and are not COPCs.

Contaminant(s) of Potential Concern (COPC) – Contaminants of interest that have been screened-in for evaluation in later analyses during the risk assessment process.

Cleanup – Actions taken to deal with a release or threat of release of a hazardous substance that could affect humans and/or the environment. The term "cleanup" is sometimes used interchangeably with the terms remedial action, removal action, response action, or corrective action.

Colloid(s) – Very small solids (that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge.

Combined Sewer Overflow (CSO) – Discharge which occurs when system storage and conveyance capacity are exceeded during large wet-weather events and sanitary wastewater and stormwater overflow directly to the river.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) – A U.S. legislative act of 1980 authorizing EPA to respond to releases or threatened releases of hazardous substances that may endanger public health or the environment (also see Superfund).

Conceptual Site Model (CSM) – A written and/or schematic representation of an environmental system and the physical, chemical, and biological processes that determine the transport of chemicals from sources through environmental media to humans and ecological receptors in the system. The CSM is often revised periodically as additional data become available at a site.

Confined Aquifer – An aquifer in which groundwater is confined under pressure which is significantly greater than atmospheric pressure.

Congener – One of many related individual chemicals having similar chemical structure but different precise composition (e.g., PCB congeners each have two phenyl rings, but may differ in the number of chlorine atoms they contain).

Column Settling Test (CST) – Test designed to determine the settling behaviour of sediment.

D

Degradation – A type of organic chemical reaction in which a compound is converted into a simpler compound in stages.

Dense Non-Aqueous Phase Liquid (DNAPL) – Dense non-aqueous phase liquids, such as chlorinated hydrocarbon solvents or petroleum fractions, with a specific gravity greater than 1.0 that sink through the water column until they reach a confining layer.

Dermal Absorption/Penetration – The process by which a chemical penetrates the skin and enters the body as an internal dose.

Dermal Exposure (Contact) – Contact between a chemical and the skin.

Desorption – The release of a chemical from the surface of a solid material (e.g., a sediment particle) to water (e.g., water in or overlying the sediment).

Detection Limit – The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.

Diffusion – The movement of particles or dissolved chemical species from higher chemical potential to lower chemical potential (such as is represented by a difference in concentration).

Dioxins/furans – A family of chemicals that all share a similar chemical structure. Dioxins, in their purest form, look like crystals or a colorless solid. Most dioxins and furans are are produced as byproducts from most forms of combustion and several industrial chemical processes.

Dredging – The removal of sediment from the bottom of water bodies. Dredging activities may be subject to regulation under Section 404 of the Clean Water Act.

Dredge Elutriate Test (DRET) – A simple laboratory test to predict the concentration of contaminants in the water column at the point of dredging. The DRET is procedurally similar to the modified elutriate test developed by the U.S. Army Corps of Engineers to predict the contaminant concentrations in effluent from a confined disposal facility. The test involves mixing sediment and site water, allowing the heavier solid particles to settle, and analyzing for dissolved and particulate-bound contaminants.

E

Ecological Risk Assessment (ERA) – The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors, including chemicals.

Ecosystem – The interacting system of interdependent biological organisms and their nonliving environmental surroundings.

Effluent – Liquid waste—treated or untreated—that flows out of a treatment plant, sewer, or industrial outfall.

Elutriate – Mixing of solids with liquids to separate or remove by washing.

Erosion – The wearing away of land surface by wind or water, intensified by land-clearing practices related to farming, residential or industrial development, road building, or logging.

Estuary – That part of the mouth or lower course of a river in which the river's current meets the sea’s tide.

Exposure – Contact between an organism or biological system and a chemical, physical, or biological agent. Exposure may be expressed as the amount in a given environmental medium (i.e., air, water, soil, sediment, or tissue) at the point of contact (see Exposure Point Concentration) or as the amount that is taken up by an organism (i.e., a dose).

Exposure Assessment – The measurement or estimation of the magnitude, frequency, duration, and route of exposure to stressors.

Exposure Pathway – The path from sources of chemicals to man and other species via soil, sediment, water, or food.

Exposure Point Concentration (EPC) – The concentration of a chemical or microbial contaminant at the location where exposure occurs.

Exposure Route – The way a chemical or microbial contaminant enters an organism after contact; i.e. by ingestion, inhalation, or dermal absorption.

Exposure Scenario – A tool used to develop estimates of potential exposure, dose, and risk. An exposure scenario generally includes facts, data, assumptions, inferences, and sometimes professional judgment about how the exposure takes place.

***Ex Situ* Treatment (soil)** – The processing of dredged sediments to transform or destroy COCs. It often involves a combination of processes or treatment to address various contaminant problems, and includes pretreatment, operational treatment, and/or effluent treatment/residual handling.

F

Flux – The transfer of water equivalant to water flow or discharge, or the transfer of a chemical substance that is the product of the water flow and substance concentraition.

Food Web Model – A graphical or mathematical model that describes interconnecting feeding relationships. Some food web models may be used to simulate bioaccumulation of chemicals from environmental media and transfer through food chains.

Fugacity – The property of a gas, related to its partial pressure, that expresses its tendency to escape or expand.

G

Gamete – A mature sexual reproductive cell, as a sperm or egg, that unites with another cell to form a new organism.

Gastropods – Any mollusk of the class Gastropoda, such as the snails, whelks, and slugs.

Groundwater – The supply of water found beneath the Earth's surface, usually in aquifers, which supply wells and springs.

Groundwater Discharge – Groundwater entering a water body (e.g., lake, river, or coastal marine waters).

Groundwater Plume – Contaminated groundwater that is moving through the subsurface by advection and dispersion.

Groundwater Seep – Groundwater discharge that is visble as it enters a water body either above or below the water line.

H

Habitat – The place where a population (e.g. human, animal, plant, microorganism) lives and its surroundings, both living and non-living.

Hazard Index (HI) – An indication of the potential for cumulative noncancer effects that is derived by summing the individual chemical hazard quotients.

Hazard Quotient (HQ) – The ratio of estimated site-specific exposure to a single chemical to a selected toxicity threshold, which is either the level at which no adverse health effects are likely to occur (i.e., the no-observed-adverse-effect level) or at which effects are likely to occur (i.e., the lowest-observed-adverse-effect level).

Hazardous Substance – From CERCLA, a hazardous substance is: "(A) any substance designated pursuant to section 311(b)(2)(A) of the Federal Water Pollution Control Act [33 U.S.C. 1321(b)(2)(A)], (B) any element, compound, mixture, solution, or substance designated pursuant to section 9602 of this title [i.e., CERCLA], (C) any hazardous waste having the characteristics identified under or listed pursuant to section 3001 of the Solid Waste Disposal Act [42 U.S.C. 6921] (but not including any waste the regulation of which under the Solid Waste Disposal Act [42 U.S.C. 6901 et seq.] has been suspended by Act of Congress), (D) any toxic pollutant listed under section 307(a) of the Federal Water Pollution Control Act [33 U.S.C. 1317(a)], (E) any hazardous air pollutant listed under section 112 of the Clean Air Act [42 U.S.C. 7412], and (F) any imminently hazardous chemical substance or mixture with respect to which the Administrator has taken action pursuant to section 7 of the Toxic Substances Control Act [15 U.S.C. 2606]. The term does not include petroleum, including crude oil or any fraction thereof which is not otherwise specifically listed or designated as a hazardous substance under subparagraphs (A) through (F) of this paragraph, and the term does not include natural gas, natural gas liquids, liquefied natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas)."

Hindcast – A method of testing a mathematical model by using data from a past event.

Hydraulic Gradient – The slope of the groundwater potentiometric surface from which the direction of groundwater flow can be predicted.

Hydrodynamics – The study of liquids in motion.

Hydrogeology – The study of the occurrence and movement of water below the earth's surface.

Hydrograph – A record of the stage and/or discharge of a river as a function of time.

Hydrophobic – Tending not to dissolve in, mix with, or be wetted by water.

I

Infauna – The aggregate of organisms that burrow into and live in the bottom deposits of the ocean.

Infiltration – The penetration of water through the ground surface into subsurface soil or the penetration of water from the soil into sewer or other pipes through defective joints, connections, or manhole walls.

***In Situ* Treatment (soil)** – Chemical, physical, or biological techniques for reducing COC concentrations while leaving the contaminated sediment mass in place.

Intertidal – Relating to the region between the high tide mark and the low tide mark.

Interstitial – Referring to the space between cells, atoms or molecules, or soil particles.

K

Kriging – A method of interpolation (named after a South African mining engineer named D. G. Krige) based on the assumption that the parameter being interpolated can be treated as a regionalized variable.

L

Leachate – Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers.

Light Non-Aqueous Phase Liquid (LNAPL) – A non-aqueous-phase liquid with a specific gravity less than 1.0. Because the specific gravity of water is 1.0, most LNAPLs float on top of the water table. Most common petroleum hydrocarbon fuels and lubricating oils are LNAPLs.

Lowest Observed Adverse Effect Level (LOAEL) – The lowest level of a stressor that causes statistically and biologically significant differences between a test sample and a control sample (i.e., sample not subjected to a stressor).

M

Matrix – The sample material in which the chemicals of interest are found (e.g., water, sediment, tissue).

Media – Specific environmental materials—air, water, soil, and biological tissue.

Mean Higher High Water – Average of the higher high water height of each tidal day over a 19-year period.

Mean Lower Low Water – Average of the lower low water height of each tidal day over a 19-year period.

Method Detection Limit (MDL) – The minimum concentration of a substance being analyzed that has a 99 percent probability of being identified.

N

National Pollutant Discharge Elimination System (NPDES) – A regulatory program enacted under the Clean Water Act, which prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or, where delegated, a tribal government on an Indian reservation.

National Priorities List (NPL) – EPA's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial action under Superfund. The list is based primarily on the score a site receives from the Hazard Ranking System. EPA is required to update the NPL at least once a year. A site must be on the NPL to receive money from the Trust Fund for remedial action.

Natural Recovery –A process in which contaminated sediments are left in place and ongoing aquatic sedimentary and biological processes are allowed to contain, destroy, or otherwise reduce the bioavailability of the contaminants in order to protect receptors.

No Observed Adverse Effect Level (NOAEL) – The highest exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered as adverse, or as precursors to adverse effects. In an experiment with several NOAELs, the regulatory focus is primarily on the highest one, leading to the common usage of the term NOAEL as the highest exposure without adverse effects.

Non-Aqueous-Phase Liquid (NAPL) – Non-aqueous phase liquids are liquids that are sparingly soluble in water. Because they do not mix with water, they form a separate phase. For example, oil is an NAPL because it does not mix with water, and oil and water in a glass will separate into two separate phases. NAPLs can be lighter than water (LNAPL) or denser than water (DNAPL). Hydrocarbons, such as oil and gasoline, and chlorinated solvents, such as trichloroethylene, are examples of NAPLs.

Non-detect – Data point for which the chemical of interest was not detected in an environmental sample.

Non-Point Sources – Diffuse pollution sources (i.e. without a single point of origin or not introduced into a receiving stream from a specific outlet). The contaminants are generally carried

off the land by storm water. Common non-point sources are agriculture, forestry, urban, mining, construction, dams, channels, land disposal, and industry.

O

Operable Unit (OU) – Portion of cleanup site with which actions are associated.

Organic Carbon (OC) Normalized – A chemical concentration in sediment adjusted for organic carbon content. The chemical concentration is divided by the fraction of sediment that is organic carbon.

Oxic – A term used to describe an environment, a condition, or a habitat in which oxygen is present.

Oxidation-Reduction Potential – The electric potential required to transfer electrons from one compound or element (the oxicant) to another compound (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

P

Pathway – An exposure pathway is the physical course a chemical, particle, or microbe takes from its source to the exposed organism.

Percent Fines – The sum of all silt and clay fractions in sediment; sediment particles passing U.S. standard sieve #230 (0.0625-mm openings).

Permeability – The rate at which a liquid or gas flows through soil or other materials.

Phenols – A class of organic chemicals, the simplest of which is phenol. Phenol and other phenols are used in manufacturing including the making of plastics, detergents, and pharmaceuticals. Phenols are also found naturally in plants and can be a product of coal oxidation.

Phthalates – A family of compounds whose primary use is as a plasticizer to increase flexibility, transparency, and durabililty of plastics. They are colorless, oily liquids with little or no odor and low volatility.

Photolysis – Decomposition of a chemical induced by light or other radiant energy.

Phytoplankton – Photosynthetic or plant constituent of plankton; mainly unicellular algae.A type of plankton classified as a plant.

Plume – A contiguous visible or measurable discharge of a substance or contaminants emanating from a given point of origin. Can be visible as, for example, a plume of smoke, or simply

measureable, as for example, elevated concentrations of contaminants in a discharge plume in a river.

Point Source – A stationary location or fixed facility from which contaminants are discharged; any single identifiable source of pollution; e.g. a pipe, ditch, ship, ore pit, factory smokestack.

Polycyclic Aromatic Hydrocarbon (PAH) – Class of chemicals that have two of more fused aromatic ring structures.

Pore Water – Water existing in the interstices (i.e., small spaces) between sediment particles.

Preliminary Remediation Goal (PRG) – An acceptable contaminant level or range of levels for a given medium that can be used to support an evaluation of remedial alternatives. Although the preliminary remediation goals are established based on readily available information, the final acceptable exposure levels should be determined on the basis of the results of the baseline risk assessment and the evaluation of the expected exposures and associated risks for each alternative.

Proximal – Situated close to.

Q

Quality Assurance/Quality Control (QA/QC) – A system of procedures, checks, audits, and corrective actions to ensure that all EPA research design and performance, environmental monitoring and sampling, and other technical and reporting activities are of the highest achievable quality.

R

Reactive Media – Material that will eliminate or reduce the availability of chemicals through physical, chemical, or biological processes.

Reasonable Maximum Exposure – The maximum exposure reasonably expected to occur in a population.

Receptor – A human demographic group (e.g., people who fish in a river) or ecological entity (e.g., species or group of species) that is potentially exposed to a stressor.

Record of Decision – A public document that explains which cleanup alternative(s) will be used at National Priorities List sites where, under CERCLA, Trust Funds pay for the cleanup.

Remedial Action – The actual construction or implementation phase of a Superfund site cleanup that follows a remedial design.

Residuals – Contaminated sediment left behind after completion of removal actions.

Rinsate – Referring to water containing low concentrations of contaminants resulting from the cleaning of containers used for sampling.

Riparian Zone – A transition habitat between the upland (terrestrial) zone and a water body resulting from frequent but not constant inundation of water. For the Study Area, the riparian zone was defined as the portion of riverbank between approximately +13 feet to +22 feet NAVD88 vertical elevation.

Risk – An estimate of the likelihood of adverse effects on human health or ecological receptors associated with exposure to given stressors.

Risk Assessment – Qualitative and quantitative evaluation of the risk posed to human health and/or the ecosystem by the actual or potential presence of a stressor (e.g., a toxic chemical).

Risk Characterization – The last phase of the risk assessment process that estimates the potential for adverse human health or ecological effects to occur from exposure to a stressor and evaluates the uncertainty involved.

Risk-Drivers – A chemical that has a significant impact on risk estimates requiring a risk management recommendation or action.

Risk Management – The process of evaluating and selecting alternative regulatory and non-regulatory responses to risk.

Risk Reduction – Lessening the risks, for example, from chemicals by lowering their concentrations, mobility, bioavailability, or toxicity, or reducing exposure of receptors.

S

Saturated Zone – The area below the water table where all open spaces are filled with water.

Sediment Management Standards (SMS) – Chapter 173-204 of the Washington Administrative Code establishing standards for the quality of surface sediments for marine, low salinity and freshwater surface sediment management standards for the state of Washington

Sediment Quality Guideline (SQG) – A sediment chemical concentration threshold that represents some documented association with no effects or a specified level of effect on benthic invertebrates. SQGs may be presented as a pair, with the lower concentration indicating a threshold below which adverse biological effects rarely occurred and the upper concentration indicating a threshold above which adverse biological effects frequently occurred in the data set used to derive the SQGs.

Sediment Quality Standards (SQS) – Standards that correspond to a sediment quality that will result in no adverse effects on biological resources.

Semivolatile Organic Compound (SVOC) – Organic compounds that volatilize slowly at standard temperature (20 degrees Celsius and 1 atm pressure).

Silt – Sediment composed of fine mineral particles that pass a 200 sieve.

Slurry Wall – An underground barrier that serves as a low-flow boundary that restricts the movement of groundwater**.**

Solubility – A measure of how much a substance will dissolve in a liquid. Aqueous solubility is the maximum concentration of a chemical that will dissolve in pure water at a reference temperature.

Sorption – Refers to the incorporation of a substance in one physical state into another in a different physical state (absorption) or the physical adherence of molecules of one substance onto those of another (adsorption).

Stormwater Conveyance System – A system for the collection and transfer of stormwater to a discharge point.

Stressors – Physical, chemical, or biological entities that can induce adverse effects on ecosystems or human health.

Superfund – The program operated under the legislative authority of CERCLA and the Superfund Amendments and Reauthorization Act that addresses both emergency removal and long-term remedial activities. The Superfund program includes establishing the National Priorities List, investigating sites for inclusion on the list, determining their priority, and conducting and/or supervising cleanup and other remedial actions.

Surface Runoff – Precipitation, snow melt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; it is a major mechanism for transport of non-point source contaminants to water bodies.

Surface Water – All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.).

Surficial – Of or relating to a surface.

Suspended Loads (Sediment) – Specific sediment particles maintained in the water column by turbulence and carried with the flow of water.

T

Toxicity Characteristic Leaching Procedure (TCLP) – Analytical procedure to simulate leaching from a soil or solid material.

Threshold – The exposure level (concentration or dose) below which a significant adverse effect is not expected or above which a significant adverse effect is expected.

Total Petroleum Hydrocarbons (TPH) – Measure of the concentration or mass of petroleum hydrocarbon constituents present in a given amount of soil or water.

Toxic Equivalent Quotient (TEQ) – The sum of a series of multiplicative products, each consisting of the concentration of an individual carcinogenic polycyclic aromatic hydrocarbon, PCB, or dioxin/furan congener multiplied by its toxicity equivalency factor.

Toxicity – The degree to which a chemical or mixture of chemicals can cause adverse effects to living organsisms. *Acute toxicity* involves harmful effects in an organism through a single or short-term exposure. *Chronic toxicity* is the ability of a chemical or mixture of chemicals to cause adverse effects, usually upon repeated or continuous exposure over an extended period, sometimes the entire life of the exposed organism. *Subchronic toxicity* is the ability of the chemical or mixture to cause effects after exposure that is intermediate between acute and chronic.

Toxicity Reference Value (TRV) – A chemical concentration (or dose) threshold that represents some level of documented effect on a particular organism from exposure to the chemical (i.e., the minimum concentration at which adverse effects have been observed, or the maximum concentration at which no adverse effects have been observed).

Toxicity Testing – Biological testing (usually with an invertebrate, fish, or small mammal) to measure the adverse effects of a chemical, effluent, or environmental sample.

Transformation (chemical) – A process that converts one chemical to another chemical by any number of chemical reaction or biological pathways.

Trophic Level – A functional classification of species that is based on feeding relationships and indicates how high on the food chain a species eats (i.e., how many potential energy transfer steps from the ultimate food source).

U

Unconfined Aquifer – An aquifer that is not confined by an overlying aquitard.

Unsaturated Zone – The area above the water table where soil pores are not fully saturated, although some water may be present. Also referred to as the vadose zone.

Urban Runoff – Stormwater from city streets and adjacent domestic or commercial properties that carries contaminants of various kinds into the sewer systems and receiving waters.

V

Vadose Zone – The zone between land surface and the water table within which the soil pores contain water that is less than saturation (except in the capillary fringe). The capillary fringe is the subsurface layer in which groundwater seeps up (by surface tension) from a water table to fill soil pores and is included in the vadose zone.

Van der Waals forces – Relatively weak electric forces (named for the Dutch physicist Johannes van der Waals) that attract neutral molecules to one another in gases, in liquefied and solidified gases, and in almost all organic liquids and solids.

Volatile – Any substance that evaporates readily.

Volatile Organic Compound (VOC) – Organic compound that generally has a boiling point below 150°C and a vapor pressure of greater than 0.1 millimeter of mercury.

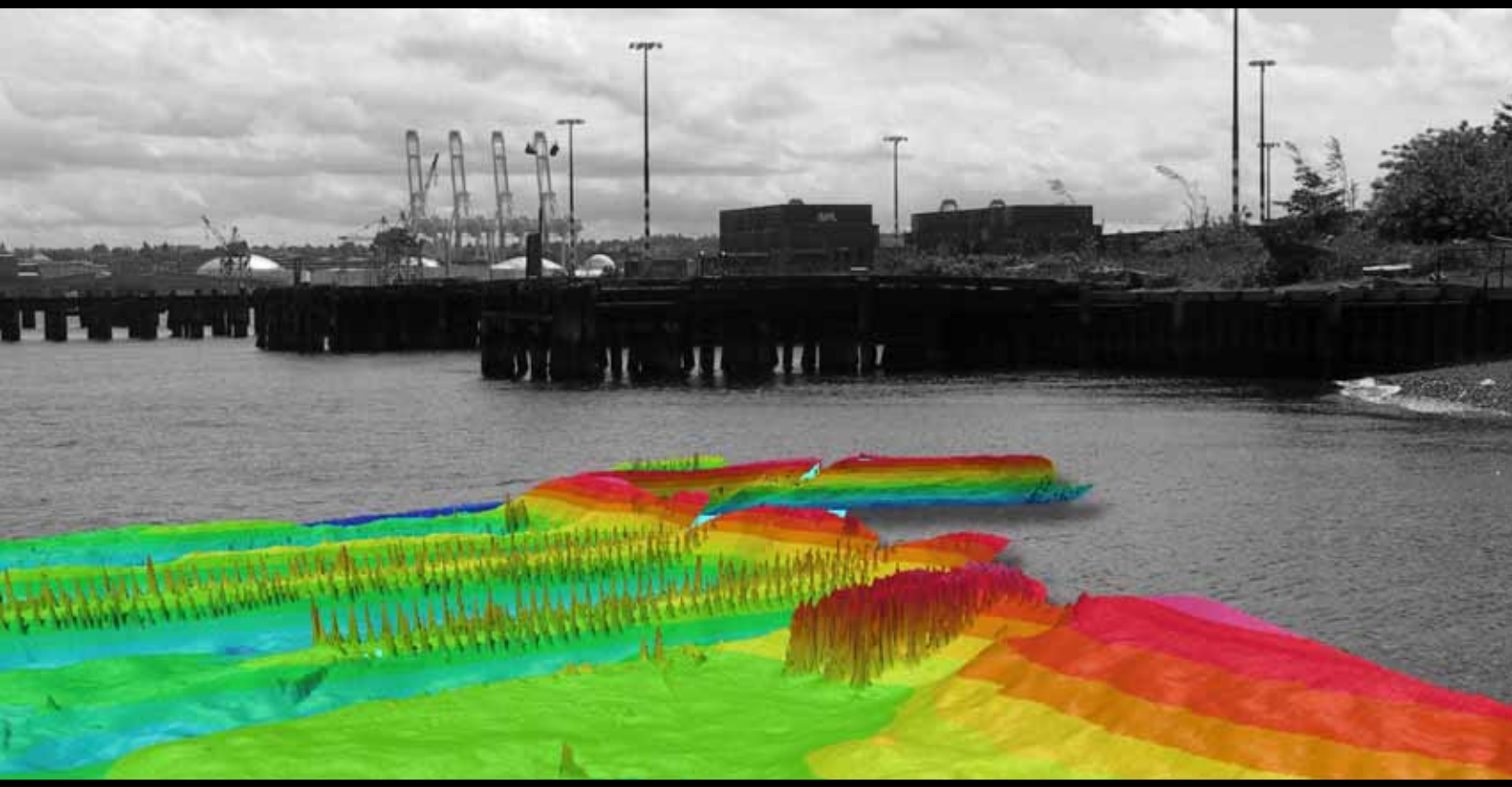
Volatilization – The transfer of chemicals dissolved in surface water to the atmosphere.

W

Water Quality Criteria – Chemical concentrations in surface water specified by environmental regulation and expected to render a body of water suitable for its designated use. Criteria are based on specific levels of chemicals that would make the water safe for aquatic life or safe for human use for drinking, swimming, farming, fish production, or industrial processes.

Weight of Scientific Evidence – The degree to which a body of scientific information supports a finding or conclusion. Considerations in assessing the weight of evidence in a risk assessment may include quality of testing methods, size and power of study design, consistency of results across studies, and biological plausibility of exposure-response relationships and statistical associations between stressors and effects.

Z

Zooplankton – Animal constituent of plankton; mainly small crustaceans and fish larvae.

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