East Waterway Operable Unit

Supplemental Remedial Investigation/ Feasibility Study

Final Feasibility Study

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LIST OF ACRONYMS AND ABBREVIATIONS

90/90 UTL	90% upper tolerance limit on the 90th percentile
µg	microgram
µg/kg	microgram per kilogram
µg/L	microgram per liter
µm	micrometer
AC	activated carbon
ADCP	Acoustic Doppler Current Profiler
AET	apparent effects threshold
API	Asian and Pacific Islanders
ARAR	applicable or relevant and appropriate requirement
ASAOC	Administrative Settlement Agreement and Order on Consent
BAZ	biologically active zone
BEHP	bis(2-ethylhexyl) phthalate
bgs	below ground surface
BMP	best management practice
BNSF	BNSF Railway Company
BSAF	biota-sediment accumulation factor
CAD	confined aquatic disposal
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
City	City of Seattle
cm	centimeter
cm/s	centimeter per second
cm/yr	centimeter per year
CMA	Construction Management Area
CO	carbon monoxide
CO_2	carbon dioxide
COC	contaminant of concern
COPC	contaminant of potential concern
County	King County
cPAH	carcinogenic polycyclic aromatic hydrocarbon
Cs-137	cesium-137
CSL	cleanup screening level

CSM	conceptual site model
CSO	combined sewer overflow
CT	central tendency
CWA	Clean Water Act
cy	cubic yard
DDT	dichlorodiphenyl-trichloroethane
DMMP	Dredged Material Management Program
DNR	Washington State Department of Natural Resources
dw	dry weight
EAA	Early Action Area
Ecology	Washington State Department of Ecology
EISR	existing information summary report
ENR	enhanced natural recovery
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ESD	Explanation of Significant Differences
EW	East Waterway
EWG	East Waterway Group (Port of Seattle, City of Seattle, and King County)
FS	Feasibility Study
FWM	food web model
g/cm^3	gram per cubic centimeter
g/day	gram per day
GRA	general response action
H:V	horizontal to vertical
HC	hydrocarbon
HHRA	human health risk assessment
HI	hazard index
HOC	hydrophobic organic contaminant
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HQ	hazard quotient
I-5	Interstate 5
ICIAP	Institutional Control Implementation and Assurance Plan
IRIS	Integrated Risk Information System
JARPA	Joint Aquatic Resource Permit Application
kg	kilogram
kg/yr	kilogram per year

L	liter
LDW	Lower Duwamish Waterway
LOAEL	lowest-observed-adverse-effect level
LOEC	lowest observed effect concentration
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
M	Moment Magnitude Scale
MDL	method detection limit
mg/kg	milligram per kilogram
MHHW	mean higher high water
MIS	multi-increment sampling
MJ	megajoule
MLLW	mean lower low water
MNR	monitored natural recovery
MTCA	Model Toxics Control Act
MUDS	Multi-User Disposal Site program
NCDF	nearshore confined disposal facility
NCP	National Contingency Plan
ng	nanogram
ng/L	nanogram per liter
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effect level
NO_x	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NPV	net present value
NRC	National Research Council
NSR	net sedimentation rate
NTCRA	non-time critical removal action
O&M	operations and maintenance
OC	organic carbon
OSV	Ocean Survey Vessel
OU	Operable Unit
Pa	Pascals
PAH	polycyclic aromatic hydrocarbon
Pb-210	lead-210
PCB	polychlorinated biphenyl
pcf	pounds per cubic foot

PEF	potency equivalency factor
$PM_{2.5}$	particulate matter with a diameter below 2.5 micrometers
PM_{10}	particulate matter with a diameter below 10 micrometers
PMA	Port Management Agreement
Port	Port of Seattle
POTW	publically owned treatment works
PQL	practical quantitation limit
PRG	preliminary remediation goal
propwash	propeller wash
PSAMP	Puget Sound Ambient Monitoring Program
PSCAA	Puget Sound Clean Air Agency
PTM	particle tracking model
RAL	remedial action level
RAO	remedial action objective
RBTC	risk-based threshold concentration
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RL	reporting limit
RM	river mile
RMC	residuals management cover
RME	reasonable maximum exposure
RNA	Restricted Navigation Area
ROD	Record of Decision
ROW	right-of-way
SCEAM	source control evaluation approach memorandum
SCL	sediment cleanup level
SCO	sediment cleanup objective
Screening Memo	Final Remedial Alternative and Disposal Site Screening Memorandum
SCUM	Sediment Cleanup Users Manual
SD	storm drain
SDOT	Seattle Department of Transportation
SHNIP	Seattle Harbor Navigation Improvement Project
SMS	Washington State Sediment Management Standards
SO_2	sulfur dioxide
SPU	Seattle Public Utilities

SQS	sediment quality standard
SRI	Supplemental Remedial Investigation
SRI/FS	Supplemental Remedial Investigation/Feasibility Study
SRZ	Sediment Recovery Zone
STE	sediment transport evaluation
STER	Sediment Transport Evaluation Report
SVOC	semivolatile organic compound
SWAC	spatially-weighted average concentration
T-18	Terminal 18
T-25	Terminal 25
T-30	Terminal 30
T-46	Terminal 46
T-102	Terminal 102
T-104	Terminal 104
TBT	tributyltin
TEF	toxic equivalency factor
TEQ	toxic equivalent
TI	technical impracticability
TIN	triangular irregular network
TOC	total organic carbon
TRV	toxicity reference value
TSCA	Toxic Substances Control Act
TSS	total suspended solids
U&A	Usual and Accustomed
UCL95	95% upper confidence limit on the mean
UECA	Uniform Environmental Covenants Act
USACE	U.S. Army Corps of Engineers
U.S.C.	United States Code
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
VOC	volatile organic compound
WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife
WDOH	Washington State Department of Health
Workplan	SRI/FS Workplan
WQC	water quality criteria

WQS	water quality standards
WSDOT	Washington State Department of Transportation
ww	wet weight
WW	West Waterway

1 INTRODUCTION

This document presents the Feasibility Study (FS) evaluation for the East Waterway (EW) Operable Unit (OU) of the Harbor Island Superfund site. This FS is the companion document to the Supplemental Remedial Investigation (SRI; Windward and Anchor QEA 2014). The EW is located in Seattle, Washington, and extends along the east side of Harbor Island (Figure 1-1). The EW is one of eight OUs or Study Areas of the Harbor Island Superfund site (Figure 1-1), which was added to the U.S. Environmental Protection Agency's (EPA's) National Priorities List in September 1983 under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. Under the oversight of EPA, this FS is being conducted by the East Waterway Group (EWG), which consists of the Port of Seattle (Port), the City of Seattle (City), and King County (County). The Port entered into the Administrative Settlement Agreement and Order on Consent (ASAOC) for the SRI/FS with EPA in October 2006 (EPA 2006), and subsequently entered into a Memorandum of Agreement with the City and County to jointly conduct the SRI/FS. For purposes of the SRI/FS, the EWG will be referenced as the entity implementing the SRI/FS under EPA oversight, rather than the Port.

The SRI/FS is being conducted in a manner that is consistent with the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988) and other applicable guidance. Where appropriate, the methods used in the EW SRI/FS were consistent with those used in the Lower Duwamish Waterway (LDW) RI/FS because the sites are immediately adjacent. The physical and site use differences between the LDW and the EW are summarized in the *Final Remedial Alternative and Disposal Site Screening Memorandum* (Screening Memo; Anchor QEA 2012a). The SRI/FS will ultimately lead to an EPA Record of Decision (ROD) selecting cleanup actions to address risks to human health and the environment in the EW OU.

As stated in the ASAOC (EPA 2006) and SRI/FS Workplan (Workplan; Anchor and Windward 2007), the purpose of the FS is to develop and evaluate a number of alternative methods for achieving the remedial action objectives (RAOs) and preliminary remediation goals (PRGs) at a contaminated site. This process lays the groundwork for proposing a selected remedy that eliminates, reduces, or controls risks to human health and the environment in compliance with CERCLA requirements.

This FS, as approved by EPA, is consistent with CERCLA, as amended (42 United States Code [U.S.C.] 9601 et seq.), and the National Oil and Hazardous Substances Pollution Contingency Plan (40 Code of Federal Regulations [CFR] Part 300), commonly referred to as the National Contingency Plan (NCP). Many guidance documents were considered in developing this FS, including the following:

- *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988)
- *Clarification of the Role of Applicable or Relevant and Appropriate Requirements in Establishing Preliminary Remediation Goals under CERCLA* (EPA 1997a)
- *Rules of Thumb for Superfund Remedy Selection* (EPA 1997b)
- *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002a)
- *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005)
- *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study* (EPA 2000a)

1.1 East Waterway Operable Unit Study Boundary

The EW OU study boundary was established by EPA as shown on Figure 1-1. The southern EW OU study boundary is also the northern study area boundary of the LDW Superfund site. The northern EW OU study boundary extends along the western pierhead line to the north until water depths reach -60 feet mean lower low water (MLLW). The study boundary follows the approximate upper edge of this naturally occurring slope at about -60 feet MLLW, then turns to perpendicularly intersect the bulkhead along Terminal 46 (T-46) along the eastern shoreline. The east and west boundaries of the EW OU are defined as areas below mean higher high water (MHHW; e.g., below 11.4 feet MLLW), and referred to in this FS as the EW OU or site.

1.2 Purpose of the Feasibility Study

The purpose of this FS is to develop and evaluate EW-wide remedial alternatives to address the risks posed by contaminants of concern (COCs) within the EW OU. This FS is based on the results of the SRI (Windward and Anchor QEA 2014), which included the baseline ecological risk assessment (ERA; [Windward 2012a]) and baseline human health risk assessment (HHRA; [Windward 2012b]), as Appendices A and B, respectively. This FS also builds on the evaluation of remedial technologies, disposal options, and remedial alternatives that were evaluated in the Screening Memo (Anchor QEA 2012a).

The SRI assembled data to identify the nature and extent of contamination in the EW, evaluated sediment transport processes, assessed current conditions within the EW, including risks to human and ecological receptors that use the EW, and identified potential sources and pathways of contamination to EW (see Sections 2 and 3). The FS uses the results of the SRI and the baseline risk assessments to identify RAOs, develop PRGs, and develop and evaluate EW-wide remedial alternatives (see Sections 4 through 10). The FS lays the groundwork for selecting a cleanup alternative that addresses risks to both human health and the environment in compliance with CERCLA requirements.

The Screening Memo (Anchor QEA 2012a) identified and screened sediment remedial technologies (e.g., dredging, capping, etc.) that may be applicable to the EW OU. It also screened potential disposal technologies for contaminated sediment, and included preliminary remedial alternatives to narrow the range of alternatives to be considered for detailed analysis in this FS. The purpose of the Screening Memo was to efficiently eliminate remedial technologies, disposal options, and alternatives that are not practicable so the FS can focus on viable remedial alternatives. This approach is consistent with EPA RI/FS guidance (EPA 1988) and contaminated sediment remediation guidance (EPA 2005).

1.3 The Feasibility Study Process

The FS process includes several steps outlined in CERCLA guidance (EPA 1988), as well as additional considerations outlined in *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005). Consistent with the LDW FS (AECOM 2012), these general steps and considerations include the following:

- Summarizing and synthesizing the results of the SRI, including the physical conceptual site model (CSM), baseline ERA and HHRA, and related documents for the EW (Sections 2 and 3)
- Establishing applicable or relevant and appropriate requirements (ARARs), RAOs, and associated PRGs (Section 4)

- Use of sediment risk-based threshold concentrations and background concentrations for risk driver COCs in the development of PRGs (Section 4)
- Estimating areas of sediment with risk driver COC concentrations above remedial action levels (RALs)[1] that are appropriate for the application of sediment remedial approaches[2] (Section 6)
- Evaluation of remedial and disposal technologies, as first described in the Screening Memo (Anchor QEA 2012a) (Section 7)
- Evaluation of general response actions, remedial technology types, and specific process options best suited to site conditions (Section 7)
- Assembling the technology types and process options into site-wide remedial alternatives, and then completing the estimate of areas, volumes, and costs for the alternatives (Section 8)
- Completing a detailed evaluation and comparative analysis of retained remedial alternatives (Sections 9 and 10)

Under CERCLA, the FS presents, evaluates, and compares the remedial alternatives for a site. Input from stakeholders (including the Muckleshoot and Suquamish Tribes and the State) will be considered by EPA during development of the final FS. After approval of the FS, EPA proposes a final cleanup remedy in a document called the Proposed Plan; this plan is then provided to the public and stakeholders for comment. After public and stakeholder comments on the Proposed Plan are evaluated, EPA selects the final remedy in a ROD, including the final RAOs and cleanup levels based on the nine remedy selection criteria specified in the NCP (40 CFR 300.430(e)(9)(iii)).

1.4 Definitions for the Feasibility Study

Definitions of regulatory terms, contaminant concentrations, various spatial areas, and time frames used in the FS are provided below. Some of these terms have site-specific definitions, but most are drawn directly from CERCLA regulations or guidance documents. In the case of

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[1] The RALs are developed in Section 6 to define areas that undergo remediation to achieve RAOs. RALs may or may not be set at the PRGs, depending on the risk pathway being addressed.

[2] The water column cannot practicably be directly remediated, but improvements in surface water quality are expected following sediment cleanup and source control measures.

new definitions, similar terms are referenced when applicable. These definitions are consistent with those used in the LDW FS (AECOM 2012).

1.4.1 Regulatory Terms

Background; CERCLA uses the terms anthropogenic (man-made) background and natural background (EPA 1997b), and EPA's sediment remediation guidance (EPA 2005) states that cleanup levels will normally not be set below natural or anthropogenic background concentrations. Washington State Sediment Management Standards (SMS; Washington Administrative Code [WAC] 173-204; Ecology 2013) use the terms regional background and natural background.

Cleanup level under CERCLA means the concentration of a hazardous substance in an environmental medium that is determined to be protective of human health and the environment under specified exposure conditions. Cleanup levels are proposed in the FS but are not finalized until the ROD.

Contaminants of concern (COCs) represent a defined set of hazardous substances that were quantitatively evaluated in the baseline risk assessments and were found to exceed risk thresholds (see Section 3 for more details).

Natural background, as defined in the SMS, represents the concentrations of hazardous substances that are consistently present in an environment that has not been influenced by localized human activities. This definition includes both substances such as metals that are found naturally in bedrock, soils, and sediments, as well as persistent organic compounds such as polychlorinated biphenyls (PCBs) that can be found in soil and sediments throughout the state as a result of global distribution of these contaminants. Whenever the term natural background is used in this FS, it means as defined in the SMS (WAC 173-204-505).

Point of compliance is defined as the point or points where cleanup levels shall be achieved.

Practical quantitation limit (PQL) is defined 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 (40 CFR 300.430(e)(2)(i)(A)(3)) allows that cleanup levels can be modified based on "factors related to technical limitations such as detection/quantitation limits for contaminants." The term PQL is synonymous with quantitation limit and reporting limit.

Preliminary remediation goals (PRGs) are specific desired contaminant endpoint concentrations or risk levels for each exposure pathway that are believed to provide adequate protection of human health and the environment based on available site information (EPA 1997b). For the FS, PRGs are expressed as sediment concentrations for the contaminants that present the principal risks (i.e., the risk drivers). PRGs are based on consideration of the following factors:

- ARARs
- Risk-based threshold concentrations (RBTCs) developed in the SRI
- Background concentrations are used to develop PRGs if protective RBTCs are below background concentrations
- Analytical PQLs if protective RBTCs are below concentrations that can be quantified by chemical analysis

PRGs are presented in the FS as preliminary cleanup levels that are used in the FS to guide evaluation of proposed sediment remedial alternatives, but they are not the final CERCLA cleanup levels. EPA will ultimately define those levels in the ROD.

Regional background is a term defined in the SMS as the concentration of a contaminant within a Washington State Department of Ecology (Ecology)-defined geographic area that is primarily attributable to diffuse sources, such as atmospheric deposition or stormwater, not attributable to a specific source or release (WAC 173-204-505(16)).

Remedial action objectives (RAOs) describe what the proposed remedial action is expected to accomplish (EPA 1999a). They are narrative statements of specific goals for protecting human health and the environment. RAOs are used to help focus development and evaluation of remedial alternatives. RAOs are derived from the baseline risk assessments and are based on the exposure pathways, receptors, and the identified COCs. Narrative RAOs form the basis for establishing PRGs (defined above).

Remedial action levels (RALs) are contaminant-specific sediment concentrations that trigger the need for remediation (e.g., dredging, capping, enhanced natural recovery [ENR], or monitored natural recovery [MNR]). Remediation levels or RALs are not the same as cleanup levels or PRGs. Remediation levels may be used at sites where a combination of cleanup actions is used to achieve cleanup levels at the point of compliance. Remediation levels, by definition, exceed cleanup levels.

Remediation Area is the area with sediment concentrations above any of the RALs that is or could be exposed to human or ecological receptors.

Risk driver hazardous substances (risk driver COCs) are used in the FS to indicate the subset of COCs identified in the baseline risk assessments that present the principal risks. Risk drivers are a subset of hazardous substances present at a site selected for monitoring and analysis or for establishing cleanup requirements.

Other COCs not designated as risk drivers will be discussed in the FS by estimating the potential for risk reduction following remedial actions. In addition, COCs may be assessed as part of the 5-year review that is conducted every 5 years once a CERCLA cleanup is completed that leaves hazardous substances on site above cleanup levels, and they may be included in the post-cleanup monitoring program.

Washington State Sediment Management Standards (SMS) include the Washington State requirements for sediment cleanup sites and are an ARAR for the EW OU of the Harbor Island Superfund site.

Total excess cancer risk is defined as the additional probability (i.e., the additional probability above the lifetime cancer risk[3]) of an individual developing cancer over their lifetime based on exposure to site-specific contaminants. In the final EW baseline HHRA (Windward 2012b) and this FS, total excess cancer risk is defined as the sum of all cancer risks for multiple contaminants and pathways for an exposure scenario. For example, total excess

[3] The lifetime risk of developing cancer in the United States is 1 in 2 for men and 1 in 3 for women (American Cancer Society 2006).

cancer risks for the clamming scenario include cancer risks associated with the dermal exposure pathway for exposure to sediment and the incidental sediment ingestion pathway.

1.4.2 Sediment Concentrations

Sediment concentrations are expressed and evaluated in the FS in two ways: 1) as individual point concentrations; or 2) as spatially-weighted average concentrations (SWACs). RBTCs were developed in the SRI and are also expressed as either point concentrations or SWACs (all defined below).

Point concentrations are contaminant concentrations in sediments at a given sampling location, where each value is given equal weight. Point concentrations are typically applied to small exposure areas (e.g., for benthic organisms with small home ranges). Point concentrations are sometimes mapped in the FS as Thiessen polygons, with each Thiessen polygon defined as an area of influence around its sample point, so that any location inside the polygon is closer to that point than any of the other sample points. Point concentrations are compared to either dry weight-based concentration thresholds, or to organic carbon (OC)-normalized concentration thresholds, depending on the contaminant.

Risk-based threshold concentrations (RBTCs) are the calculated sediment and tissue concentrations estimated to be protective of a particular receptor for a given exposure pathway and target risk level. RBTCs are based on the baseline risk assessments and were derived in the SRI. Tissue RBTCs are used to derive sediment RBTCs that are predicted to reduce tissue concentrations to protective levels for human health seafood consumption based risks or fish and wildlife-based risks. Sediment RBTCs are used along with other site information to set PRGs (defined above) in the FS.

Spatially-weighted average concentrations (SWACs) are similar to a simple arithmetic average of point concentrations over a defined area, except that each individual concentration value is weighted in proportion to the sediment area it represents. SWACs are widely used in sediment management because they are more accurate at calculating area-wide average concentrations than arithmetic-based averages where data points are not evenly distributed. The selected area over which a SWAC would be applied may be adjusted for a specific receptor or activity. For example, EW-wide SWACs may be appropriate for estimating human health risks associated with consumption of resident seafood, but not for direct contact risks from the collection of clams (which are harvested only in certain areas). In this manner, site-wide or area-wide SWACs are intended to provide meaningful estimates of exposure point concentrations for human or ecological receptors.

SWAC calculations have been used at several large Superfund sediment sites to evaluate risks and cleanup levels (e.g., LDW, Fox River, Hudson River, Housatonic River, and Willamette River). For example, the Lower Fox River ROD selected a total PCB remedial action level of 1 milligram per kilogram (mg/kg) dry weight (dw) in sediment to achieve a site-wide SWAC of 250 micrograms per kilogram (µg/kg) dw over time.

95% upper confidence limit on the mean (UCL95) is a statistically derived quantity associated with a representative sample from a population (e.g., sediment or tissue chemistry results from a waterbody) such that 95% of the time, the true average of the population from which the sample was taken will be less than the quantity statistically derived from the sample dataset (e.g., 95% of the time, the true average sediment contaminant concentration for the waterbody will be less than the UCL95 based on sediment chemistry sample results). The UCL95 is used to account for uncertainty in contaminant concentrations and to ensure that contaminant concentrations are not underestimated.

1.4.3 Terms Related to Time Frames

The remedial alternatives refer to different time frames when describing different aspects of the remedy, such as the number of years to design or implement a remedy, or the number of years to achieve the RAOs. For clarity, the terms related to time frames used in the FS are defined below.

Construction period refers to the time assumed necessary to construct the remedial alternatives. For the EW, this period is assumed to begin 5 years following issuance of the ROD to allow sufficient time for priority source control actions; negotiation of orders or consent decrees; initial remedial design and planning, including remedial design sampling and analysis; baseline monitoring; and permitting and obtainment of authorizations.

Monitored natural recovery (MNR) period is the time during which the MNR-specific level of monitoring is needed in MNR areas. Monitoring conducted during the MNR period will assess whether sufficient progress is being made toward achieving cleanup objectives, or, alternatively, whether contingency actions (which may include modifying technologies or methods of applications) are warranted to meet the project goals (e.g., the SMS).

Natural recovery is a term used in this FS to describe the time after remediation during which natural recovery processes are expected to continue reducing surface sediment concentrations toward natural background-based PRGs. Natural recovery is tracked by site-wide monitoring; however, unlike MNR, natural recovery does not include location-specific monitoring or contingency actions.

1.5 Document Organization

The remainder of this document is organized as follows:

- Section 2 (Environmental Setting, SRI Summary, and Current Conditions) builds on the key findings of the SRI and focuses on the site characteristics that affect the selection of remedial technologies and assembly of alternatives. The FS dataset, which is the same dataset included in the SRI, is summarized in this section.
- Section 3 (Risk Assessment Summary) summarizes the results of the baseline ERA (Windward 2012a) and HHRA (Windward 2012b) and the RBTCs for risk drivers, which were derived in the SRI.
- Section 4 (Remedial Action Objectives and Preliminary Remediation Goals) presents the recommended RAOs, ARARs, and identifies PRGs for the FS.
- Section 5 (Predictive Evaluation Methodology for Site Performance Over Time) presents the framework and analysis of sediment movement in the EW and describes the methods for predicting changes in sediment chemistry.
- Section 6 (Remedial Action Levels) presents the RALs and corresponding COC footprints.
- Section 7 (Identification and Screening of Remedial Technologies) screens a broad array of remedial approaches and identifies representative technologies that may be applied to the site.

- Section 8 (Development of Remedial Alternatives) describes EW-wide remedial alternatives designed to achieve the RAOs.
- Section 9 (Detailed Analysis of Alternatives) screens the remedial alternatives individually using CERCLA guidance. The risk reduction achieved by each remedy is also discussed.
- Section 10 (CERCLA Comparative Analysis) compares the remedial alternatives on the basis of CERCLA evaluation criteria.
- Section 11 (Conclusions) summarizes the key findings of the FS and presents a general remedial approach for cleaning up the EW.
- Section 12 (References) provides publication details for the references cited throughout the text.

Tables appear within the text after first mention, and figures appear at the end of each section. Details that support various analyses in the FS are presented in the appendices, as follows:

- Appendix A: Supplemental Information for Selection of PRGs
- Appendix B: Sediment Modeling Memoranda
- Appendix C: Remediation Area Evaluation
- Appendix D: Cap Modeling
- Appendix E: Cost Estimate
- Appendix F: Volume Calculations
- Appendix G: Monitoring Program
- Appendix H: Remaining Subsurface Contamination
- Appendix I: Short-term Effectiveness Metrics
- Appendix J: Detailed Calculations and Sensitivity Analyses for Predictive Evaluation of Site Performance Over Time and Recontamination Potential
- Appendix K: Direct Atmospheric Deposition Evaluation
- Appendix L: Alternatives Screening

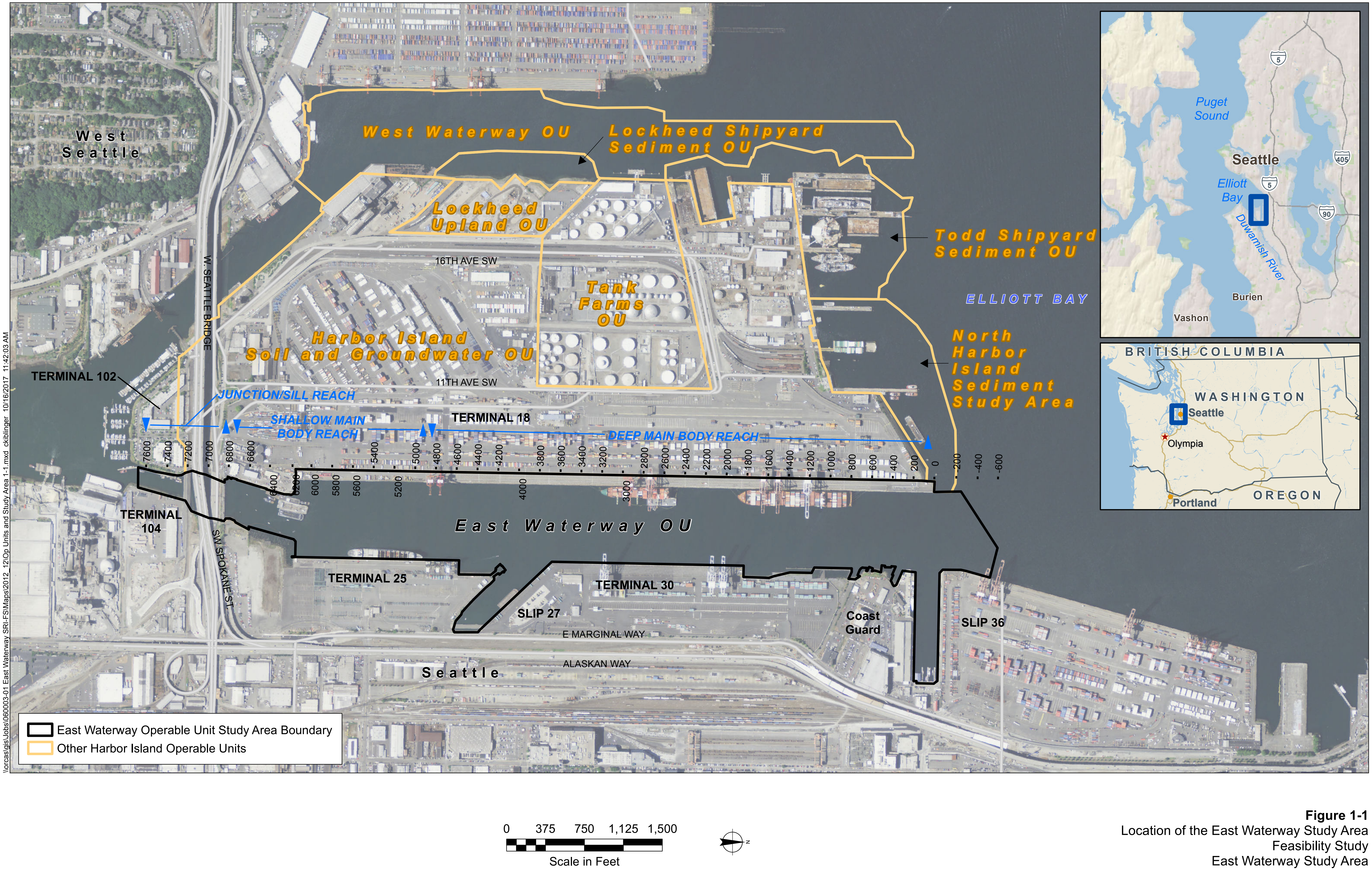

Figure 1-1
Location of the East Waterway Study Area
Feasibility Study
East Waterway Study Area

2 ENVIRONMENTAL SETTING, SRI SUMMARY, AND CURRENT CONDITIONS

This section summarizes the EW environmental setting, history, and key findings of the SRI relevant to the FS. Additional details beyond those summarized in this section are presented in the SRI (Windward and Anchor QEA 2014).

2.1 Environmental Setting

The EW is located approximately 1 mile southwest of downtown Seattle, in King County, Washington (Figure 1-1). It is part of the greater Green/Duwamish River estuary, which includes the freshwater/saltwater interface extending as far as 10 miles upstream, through the LDW, from the mouth of the EW at Elliott Bay. The EW is primarily used for shipping and as a cargo transport terminus. Detailed descriptions of EW land and waterway use are provided in Section 2.9.

The Green/Duwamish River drains approximately 362,000 acres of the Green/Duwamish watershed, flowing northward to its terminus in Puget Sound at Elliott Bay. The last 6 miles of the river were straightened and channelized into a commercial waterway for ship traffic, and is designated the LDW for approximately 5 miles, starting at the southern terminus of Harbor Island. After this point, the LDW splits into the EW and the West Waterway (WW), surrounding Harbor Island. The EW and WW extend from the southern end of Harbor Island to the island's northern end at Elliott Bay. The EW runs along the eastern shore of Harbor Island.

The EW OU of the Harbor Island Superfund site is located immediately downstream from, and adjacent to, the LDW Superfund site. The northern and southern study area boundaries for the EW OU are shown in Figure 1-1. The east and west boundaries of the EW OU are defined by MHHW, which is equivalent to 11.4 feet MLLW.

The EW OU is approximately 8,250 feet long and for most of its length is 750 feet wide. It is channelized and has a south-to-north orientation. The Port uses a measurement system along the length of the Terminal 18 (T-18) berth face, comprised of "stationing" or "station markers." The system is measured in feet from the northern end of Harbor Island (Station 0) to near the southern end of the EW (Station 7700) and is used by the Port to define the extents of the berths. The station markers are shown on Figure 2-1 and referenced throughout this FS.

Two slips are present along the eastern side of the EW. Slip 36 is oriented in an east/west direction and located from approximately Stations -100 to 200. Slip 27 is oriented in a northwest/southeast direction and located from approximately Stations 3800 to 4600. A shallow area off the northwest corner of Terminal 25 (T-25) and adjacent to Slip 27 is referred to as the “Mound Area” (Figure 2-1).

For the purposes of the SRI/FS, the following three reaches have been identified in the EW (Figure 2-1):

- **Junction Reach (Stations 7200 to 7650)**, which is the southern portion of the OU that adjoins the LDW
- **Sill Reach (Stations 6800 to 7200)**, which is a relatively shallow section of the OU just north of the Junction Reach
- **Main Body Reach (Stations 0 to 6800)**, which is north of the Sill Reach and comprises most of the EW OU

The Main Body Reach has been further subdivided into the following two sections (Figure 2-1):

- **Deep Main Body Reach (Stations 0 to 4950)**, with an authorized depth of -51 feet MLLW
- **Shallow Main Body Reach (Stations 4950 to 6800)**, which is located south of historical maintenance dredging activities and is generally shallower with an authorized depth of -34 feet MLLW

The Junction and Sill reaches are frequently discussed in combination in this report and are sometimes referred to as the Junction/Sill Reach. Recent EW dredge history is discussed in Section 2.14.3.

2.2 Site History and Current Configuration

Industrial development of the EW began immediately following the channelization of the Duwamish River and filling of surrounding Elliott Bay tidelands. Prior to filling, the Elliott Bay tidelands extended east of the site to the current location of Interstate 5 (I-5). Figure 2-2 depicts the approximate extent of the tidelands adjacent to the EW and tidelands associated with the historical meanders of the lower Duwamish River. Dredging of the Elliott Bay tidelands from 1903 to 1905 created the EW, which provided some of the fill materials for construction of the upland areas to the west (Harbor Island) and east (EPA 1993). By 1909, Harbor Island and the land east of the EW was created using dredge fill removed from the Duwamish River or sluiced from Seattle regrade projects (EPA 1993).

The construction of Harbor Island allowed further development of the EW. The EW was initially dredged to a minimum navigable depth of -30 to -40 feet MLLW and widened to 750 feet. Slip 27 was created along the eastern shore and dredged to a depth of -28 feet MLLW. By 1919, the EW, WW, and LDW were authorized as federal navigation channels by Congress (March 2, 1919). The EW was maintained at -40 feet MLLW along most of the 750-foot-wide portion in the mid-1920s. Slip 36 was constructed in 1927 and originally dredged to -35 feet MLLW.

The federal navigation channel information is based on information in the Water Resources Development Act, as summarized in the Port of Seattle Series No. 36 (USACE 2002). The federal navigation channel in the EW currently extends from beyond the north EW study boundary to the Spokane Street Bridge, which is approximately Station 6840 (Figure 2-1). The federal navigation channel is 450 feet wide from Stations 0 to 4950. It is 700 feet wide from Stations 4950 to 6140 and 400 feet wide from Station 6140 to the Spokane Street Bridge (Station 6840). The full federal navigation channel width is authorized to -51 feet MLLW from Stations 0 to 2970 (450 feet wide). It is also authorized to -51 feet MLLW along the western 250 feet from Stations 2970 to 3250 and the western 170 feet from Stations 3250 to 3590. The federal navigation channel is authorized to -34 feet MLLW south of Station 2970. This -34-foot-wide section is 200 feet wide from Stations 2970 to 3250, 280 feet wide from Stations 3250 to 3590, and 450 feet wide from Stations 3590 to 4950. South of Station 4950, it is authorized at -34 feet MLLW to the Spokane Street Bridge.

2.3 Bathymetry

The most recent bathymetric survey within the EW was completed in January 2010 and is presented in Figures 2-3a and 2-3b. Cross-sections demonstrating representative portions of each reach and slip are presented on Figures 2-4a through 2-4d. Current bathymetry within the federal navigation channel shows that the authorized elevation of -51 feet MLLW is met (or deeper) from Station 0 (i.e., mouth of the EW) to Station 4950 (i.e., 4,950 feet upstream of the mouth of the EW), with the exception of the “Mound Area.” Some areas within the northern portion of the federal channel reach -60 feet MLLW. Bathymetry in areas north of the northern EW OU study boundary (i.e., within Elliott Bay) quickly become much deeper than -60 feet MLLW, reaching elevations deeper than -200 feet MLLW. Along T-18, elevations south of Station 4950 generally decrease to -37 feet MLLW or shallower. Along T-25 (Stations 4600 to 6150), elevations in the berth area are approximately -50 feet MLLW.

Mudline elevations rise to between -13 and -6 feet MLLW in the Sill Reach, in the vicinity of Spokane Street and the West Seattle Bridge (DEA 2010), and then drop to -25 feet MLLW through the Junction Reach. Sediments comprising the Sill Reach under and between the bridges within the Spokane Street corridor have never been dredged following original construction, based on historical records from the U.S. Army Corps of Engineers (USACE). The shallow water depths in this area form a physical constriction across the entry to the EW that can affect flow from the Duwamish River primarily during higher flow events.

Current Port operational berthing elevation requirements vary based on location in the EW. Along T-18 between Stations 0 and 4950, the berthing elevation requirement is -51 feet MLLW. Along T-25 and Terminal 30 (T-30), berthing elevation requirements are -50 feet MLLW. The Port’s requirement for berthing in Slip 27 is generally -40 feet MLLW. In Slip 36, U.S. Coast Guard (USCG) berthing requirements are generally -40 feet MLLW. Dredging activities conducted since 2000 to maintain required navigation and berthing elevations are described in Section 2.14.3.

2.4 Aquatic Ownership

The main body of aquatic land in the EW is owned by the State of Washington and managed by the Washington State Department of Natural Resources (DNR) between the pierhead lines (Figure 2-5). Land located within the pierhead line is state-owned but managed by the Port through a Port Management Agreement (PMA). This area includes all aprons that extend approximately 100 feet from the Port's upland parcel boundary.

Portions of the aquatic area within the EW are not state-owned. South of the Spokane Street corridor, the Port owns the entire width of the EW. The Port also owns all of Slip 27, including the vacated portion of the South Forest Street right-of-way (ROW) and Pier 27 (south side of Slip 27). A portion of aquatic area along Pier 24 that formerly contained timber decking is also owned by the Port. All of Slip 36 is owned by USCG.

2.5 Hydrodynamics

The EW is primarily saltwater, but receives freshwater flows from the Green/Duwamish River watershed. Hydrodynamic circulation in the EW is controlled by tidal exchange with Elliott Bay to the north and freshwater inflow from the Green River (through the LDW) from the south. The EW can be generally described as two-layer flow, with a wedge of saltwater extending from Elliott Bay upstream through the EW and into the LDW underneath a layer of fresher water flowing from the Green River.

The EW also receives freshwater discharges from 39 outfalls (Figure 2-1). The discharges are intermittent, and the relative contribution of freshwater flows from the outfalls is small in comparison with flows from the Green/Duwamish River. A complete summary of the hydrodynamic modeling conducted in the EW is included in the Sediment Transport Evaluation Report (STER; Anchor QEA and Coast & Harbor Engineering 2012) and summarized in the SRI (Windward and Anchor QEA 2014). The evaluation of solids loading from the various water sources is presented in Section 5.

The EW is subject to tidal forcing from Elliott Bay, which is characterized by mixed semi-diurnal tides (two high and two low tides per day that are not equal in height). The average tidal range (MLLW to MHHW) measured at the Seattle waterfront is 11.4 feet. The highest and lowest expected tidal heights are +13 and -3.5 feet MLLW, respectively (National Oceanic and Atmospheric Administration [NOAA] Station ID 9447130).

2.6 Sediment Characteristics and Stratigraphy

A summary of surface and subsurface existing grain size, total solids, and total organic carbon (TOC) data is presented in the SRI (Windward and Anchor QEA 2014). These data indicate that most sediment samples consisted primarily of clay and silty sand, with an average of approximately 40% sand and 50% fines[4] (total silt and clay). More fines are present in sediments in the central and northern portions of the EW than in the vicinity of the Spokane Street corridor (Figure 2-6), due to shallower water and higher tidal velocities in the Spokane Street corridor. Total solids content is generally between 40% and 60% in surface and subsurface sediment. Surface sediments contain less than 2% TOC over nearly all of the EW, with a mean of 1.6% and small areas with TOC above 2%, including Slip 27 (Figure 2-7). Generally, TOC values in the subsurface layers remain similar to surface sediments throughout the upper 5 feet, but drops to a mean 0.7% in sediment deeper than 5 feet below mudline.

Not all areas of the site below MHHW contain sediment, as shown on Figures 2-6 and 2-7. Underpier areas are armored with riprap and generally contain sediment only in the lower portions of the slope. The extent of sediment has been mapped using jet probe transects[5] conducted in 1997 and 1998 along T-18, and in 2000 along T-25 and T-30. The extent of sediment in underpier areas in Slips 27 and 36 were estimated by comparing current bathymetry to design or as-built drawings for the armored underpier slopes.

2.6.1 Grain Size Composition

2.6.1.1 Surface Sediment

Surface sediment (i.e., the top 10 centimeters [cm]) primarily consists of silty sands and sandy silts. Measured sand fractions range from 8% to 95% with a mean concentration of 50%; fines (silt and clay) fractions range from 1% to 92% with a mean concentration of 40%. The majority of the samples (93%) contain various amounts of gravel ranging from 0.01% to

[4] Site-wide, the standard deviation for fines is 23%.

[5] Jet probing is conducted by a diver using probe with a jet of water. The jet of water allows the probe to penetrate deeper into the sediment by loosening compacted sediment below the mudline. The jet probe transects provide elevations and locations of exposed (i.e., not buried by sediment) riprap along the slope and the lower extent of buried rock along the slope under the pier.

68%, with a mean concentration of 8%. Spatially, the Deep Main Body Reach contains lower portions of fines (less than 60% fines) with the exception of a few areas between Stations 2000 to 3400 with higher percent fines (greater than 60% fines). Higher fines percentages tended to occur within the Shallow Main Body Reach, at the eastern end of Slip 36, and the northern portion of Slip 27 and vicinity. The fines content of surface sediment tends to be low in the Junction and Sill Reaches.

2.6.1.2 Subsurface Sediment

Available subsurface sediment (i.e., deeper than 10 cm) physical characteristics are summarized by the stratigraphic groupings and layers (see Section 2.6.2). Areas with engineered fill, anthropogenic fill, and sand cover layers (typically shallow, upper 1 foot below mudline) contain all grain sizes, but were predominantly composed of sand and gravel. The recent and upper alluvium units (0 to 5 feet below mudline) primarily consist of fines (silt and clay) with the percent of sand increasing with depth. Gravel-sized particles (including shells) are primarily present in the upper layers (i.e., 0 to 3 feet below mudline). Below 5 feet in the lower alluvium, grain size primarily consists of sand with lesser amounts of fines than upper units and trace amounts of gravel.

2.6.2 Stratigraphy

Sediment was grouped into three stratigraphic units identified for the EW based on multiple lines of evidence, but primarily on density, color, sediment type, texture, and fill horizons (e.g., sand cover). Other information used to delineate these units included presence of anthropogenic or engineered materials, bathymetry, proximity to shoreline, and dredge history. The three units are comparable to the stratigraphy identified in the LDW RI, but differ slightly in composition based on the deltaic setting of the EW (Windward 2010a). EW sediment typically includes softer, recent sediments (i.e., silt) overlying alluvial, deltaic sediments that overlie deeper alluvial, deltaic deposits associated with early and pre-industrial time periods. In some areas, dredging and site use have altered the depths at which these units outcrop compared to initial deposition. For example, the deeper alluvial units were identified in the surface in several cores collected from the Deep Main Body Reach, which is more frequently dredged and to deeper depths than other portions of the site. The primary stratigraphic units are described in detail below, from top (i.e., mudline) to bottom of core.

- **Recent** –This upper unit consists of recently deposited material dominated by unconsolidated organic silt and inorganic silt. The surface fraction of silt often contains fine sand and gravel. This material is characterized by higher moisture content, soft to medium stiff density, smooth and homogenous texture, and higher visible organic matter compared with the underlying materials. Shell fragments, decomposed wood, and anthropogenic materials are present scattered throughout the unit (rather than in distinct layers as is common in lower units). A hydrogen sulfide odor was common in the samples, typical of reduced conditions. The Recent unit is encountered in subsurface cores between 0 and 10 feet below mudline.
- **Upper Alluvium/Transition**[6] – This middle unit forms a transitional bed between Recent and Lower Alluvium units. The Upper Alluvium unit has characteristics that are often a mix of the units lying above and below it. It consists of a mixture of silty sand and sandy silt matrices with a higher density and a higher percentage of sand compared with the Recent unit. Within this layer, stratified beds composed of silty sand or silt are present, as well as lenses (pockets) of silt. Organic silt, layers of decomposed wood, and shell fragments were often present in the samples. Some multicolored sand grains (e.g., red, beige, black, white, and gray) are located within the units. The Upper Alluvium unit is encountered in subsurface cores between 0 and 9 feet below mudline.
- **Lower Alluvium/Native**[7] – This basal unit is predominantly a sand matrix with laminated and stratified beds of slightly silty to silty sand, and silt. The sand matrix consists of multicolored grains of red, beige, black, white, and gray. Layers of undecomposed wood and shells were often present in the samples. The Lower Alluvium sand unit typically grades to stiff, inorganic silt as depth increases. This unit is encountered between 0 and 13 feet below mudline.

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[6] The term Upper Alluvium is synonymous with the term Transition used in the subsurface sediment data report (Windward 2011).

[7] The term Lower Alluvium is synonymous with the term Native used in the subsurface sediment data report (Windward 2011).

In addition to the primary stratigraphic units, three veneers overlie the existing sediment stratigraphy in discrete locations. These veneers are described below:

- **Engineered Fill** – This layer was present in cores located in close proximity to the shoreline. The composition of Engineered Fill was dominated by light to dark gray, sub-rounded, gravelly sand and sandy gravel. Gravel and cobbles were up to 3 inches in diameter. Engineered Fill has been designated based on proximity to known developmental activities associated with slope and keyway armoring activities.
- **Anthropogenic Fill** – This layer was present in cores located in close proximity to the shoreline. The composition of Anthropogenic Fill is gray to black, sub-rounded gravelly sand to coarse gravel. Anthropogenic Fill has been designated where no known development activities have occurred on the slope.
- **Sand Cover –** The sand cover was placed between Stations 3000 and 4900 during the Phase 1 removal, which was completed in 2005 (Anchor and Windward 2005). Sand cover is present in the top 1 foot of cores collected from this area. The sand cover is primarily very fine to very coarse-grained brown sand that was distinctly different in appearance from other strata within the EW based on observations of color and sorting.

2.7 Hydrogeology

The hydrogeology of the EW has been influenced both by natural and anthropogenic events (e.g., channel straightening, dredging, and filling), especially channelization of the EW and placement of fill in the east and west uplands. The EW is a channelized portion of the Green/Duwamish River delta. It is located at the north end of the Greater Duwamish Valley, and rests in a north-south trending, glacially scoured trough bounded by glacial drift uplands deposited during repeated Pleistocene glaciations (approximately 15,000 years ago). The trough contains post-glacial alluvium up to 200 feet thick (Weston 1993). The trough is bounded by upland plateau regions composed of thick sequences of Pleistocene glacial deposits.

The aquifer in the vicinity of the EW is a shallow, unconfined aquifer within fill and alluvial, deltaic, and estuarine sediments. Shallow groundwater in the adjacent nearshore areas flows primarily toward the EW and Elliott Bay. Most of the fill in the east and west uplands is hydraulic fill dredged from the channel of the Duwamish River, estimated to be 15 to 35 feet below ground surface (bgs) in the east uplands and between 3 to 15 feet bgs in the west uplands (Harbor Island). Beneath the alluvium, very dense, till-like glacial sediments were measured at depths ranging from approximately 115 to 135 feet bgs (GeoEngineers 1998). Groundwater in the nearshore environment is generally characterized as follows:

- Freshwater overrides denser saltwater and thereby confines freshwater discharge to the upper portion of the aquifer near MLLW
- Upland groundwater mixes with saline groundwater prior to discharging at the shoreline, meaning that there is little to no direct discharge of freshwater to the EW; rather it is all tidally mixed
- Tidal influx results in dilution and attenuation of groundwater between nearshore wells and the shoreline

2.8 Existing Structures and Shoreline Conditions

The EW shoreline is highly developed, primarily composed of over-water piling-supported piers, riprap slopes, seawalls, and bulkheads for industrial and commercial use. Throughout the entire length of the EW, approximately 60% of the EW shoreline contains over-water piers (aprons) above riprap slopes (along T-18, T-25, T-30, T-46, and in Slips 27 and 36; see Figures 2-8 through 2-10). Another 30% contains exposed shoreline, nearly all of which is armored with riprap (including the entire area south of the Spokane Street Bridge corridor; Figure 2-8). A portion of the shoreline area does contain some small unarmored areas below the extent of armor. The remaining 10% is comprised of steel sheetpile bulkheads (Figure 2-8). The Existing Information Summary Report (EISR) provides details on existing structures and utility information (Anchor and Windward 2008a).

The Screening Memo describes critical site restrictions that affect implementability of specific remedial technologies, including site access, physical obstructions and structural conditions, water depths, and navigation and other site uses (Anchor QEA 2012a). Based on these factors, Construction Management Areas (CMAs), which represent similar site restriction conditions, were presented in the Screening Memo (Anchor QEA 2012a) and are further discussed in regard to implementability constraints during development of remedial alternatives in Section 7.

The shoreline within Slip 27 and Slip 36 is predominantly armored riprap with extensive pier structures, although the southern shore of Slip 27 has an adjacent intertidal bench that was constructed during re-armoring of the Port property. A limited number of small areas of exposed intertidal sediment are present above the riprap slopes in locations along the eastern shoreline of the waterway, including at the head of Slip 27 (Figure 2-11).

The typical concrete wharves along the Main Body Reach in the EW are 100 feet wide from the outer edge (fender line) to the inner bulkhead, which intersects the mudline at +9 feet MLLW. Areas below the bulkheads are typically engineered riprap slopes to approximately -50 feet MLLW (with some areas to -40 feet MLLW). Representative engineered riprap slopes are shown on Figure 2-9 (T-18) and Figure 2-10 (T-25 and T-30).

Four bridge structures pass over the southern end of the EW in the Spokane Street Bridge corridor (Figure 2-8). These are operated and maintained by the Seattle Department of Transportation (SDOT; Spokane Street Bridge and SW Klickitat Way between Terminal-102 [T-102] and Terminal [T-104]), Washington State Department of Transportation [WSDOT; West Seattle Bridge], and BNSF Railway Company [BNSF] [Railroad Bridge immediately adjacent to SW Klickitat Way]). A 34-foot-wide truck bridge is also present across the head of Slip 27 between T-25 and T-30. Further information on existing structures is contained in the EISR (Anchor and Windward 2008a) and Screening Memo (Anchor QEA 2012a). In the vicinity of the bridge structures, a combined sewer transfer line that crosses the EW is buried approximately 24 feet below the mudline (HDR 1997).

A communication cable crosses the EW between T-18 and the northern portion of T-30 (Figure 2-1). This cable was originally buried between -61 and -66 feet MLLW in 1972 in an armored trench. The location shown on Figure 2-1 is based on design drawings; however, this location slightly changed following repair due to a vessel anchor incident at T-18. Along T-18, the approximate crossing was located at Station 1850. Along T-30, the approximate crossing location is indicated by a visible marker on the shore at Station 1550. Mudline elevations in the footprint of the cable crossing range from -53 to -59 feet MLLW (2 to 8 feet below mudline) in the federal channel and berth areas (Oates 2007). This area is designated as a unique CMA (see Section 7) due to the presence of the communication cable, which affects assumptions for some remedial technologies in this area.

The extensive shoreline development and utility crossings in the EW affect the remedial alternatives that could be practicably implemented. The distribution and types of overwater and in-water structures within the EW are important to consider in this FS because they represent areas where:

- Pile-supported structures, engineered or non-engineered steep slopes, vertical bulkhead walls, outfall structures, and cables may be damaged or undermined by sediment remediation, such as removal.
- Remedial alternatives need to be engineered to allow navigation depths to be maintained.
- Piles and unused or dilapidated structures (e.g., bulkheads or docks) may need to be removed or modified to implement the remediation.
- Remediation may be difficult because of restricted access, presence of vessels, and armored conditions of the sediment and shoreline.
- Vessel maneuvering associated with commercial EW activities can cause scour.
- Outfalls may require armoring of adjacent sediment caps or backfill material to prevent undermining during removal actions.

2.9 Adjacent Land and Waterway Uses

2.9.1 Adjacent Facilities and Infrastructure

The EW is an active industrial waterway used primarily for container loading and transport. Land use, zoning, and land ownership along the EW are consistent with active industrial uses (Figure 2-5). The sides of the EW contain hardened shorelines with extensive overwater structures, commercial and industrial facilities, and other development.

Thirty-nine outfalls are present in the EW, including 36 storm drains (SDs), one combined sewer overflow (CSO), and two CSO/SDs (Figure 2-1). The two outfalls that are shared by separated SDs and CSOs are the Hinds and Lander CSO/SDs. These CSO/SD outfalls and the Hanford CSO outfall discharge along the eastern shoreline of the EW. The stormwater-only outfalls are located along both sides of the waterway.

2.9.2 Navigation and Berthing

The EW north of the Spokane Street corridor experiences regular vessel traffic of various sizes and types. Most vessel traffic consists of container vessels and assorted tugboats moving into and out of the EW. Each container ship requires at least one tugboat to maneuver the ship during docking and undocking. Container ships berth at T-18, T-25, and T-30 (Figure 2-5). Cruise ships also frequented the EW from 2002 to 2008, when the southern portion of T-30 was being used as a cruise ship terminal.

Numerous barges and tugboats are moored at the head of the EW along what is currently Harley Marine Services, which includes Olympic Tug and Barge as a subsidiary (Figure 2-5). At the northeast end, along T-18, tug and barge traffic utilize the Kinder Morgan petroleum products transfer facility (Figure 2-5).

Additional navigation and berthing occurs in Slips 27 and 36. Slip 27 is used by the Port for temporary moorage of barges (along Pier 28), which are maneuvered by tugboats. USCG vessels frequent Slip 36, which serves Pier 36 (south) and Pier 37 (north). USCG moors numerous vessels in Slip 36, including USCG icebreakers, cutters (longer than 65 feet), and gunboats. Only USCG vessels currently use this slip regularly, but the U.S. Navy occasionally uses this slip.

South of the Spokane Street corridor, recreational, and commercial boats access the Harbor Island Marina (T-102) from the LDW. Along the T-102 shoreline within the EW, the Port leases out moorages on a 750-foot-long dock for commercial use. The Spokane Street corridor itself prohibits any type of boat passage, except at low tide by small, shallow-draft boats (e.g., kayaks and skiffs).

USACE completed a draft Seattle Harbor Navigation Improvement Project (SHNIP) Feasibility Report and Environmental Assessment in August 2016 (USACE 2016). Several alternatives for deepening and widening the federal navigation channels in the EW and WW were evaluated. The draft recommended plan includes the deepening and widening of the federal navigation channels in both the EW and WW. Within the EW, the recommended plan would deepen and widen the entrance channel north of Station 0 and the navigation channel south to Station 4950. The Seattle Harbor Navigation Improvement Project

Feasibility Report and Environmental Assessment is expected to be finalized in mid-2018. Harbor deepening and widening is a potential future condition for the EW; however, no decision has been made to proceed with the recommended navigation improvement project for either the EW or WW, as implementation depends on approval and funding by the federal government and other parties. All alternatives in the Seattle Harbor Navigation Improvement Project Feasibility Report and Environmental Assessment assume that any deepening activities would occur following cleanup of the EW. Further, any of the EW remedial alternatives presented in this FS are compatible with the potential navigation improvement alternatives presented in the USACE report. A requirement of the navigation improvement project is that it will not reduce the environmental protectiveness of the remedy in the EW. The potential navigation improvement project is discussed further in the context of the remedial alternatives in Section 8.3.4.

2.9.3 Tribal and Recreational Use

The EW is part of the Suquamish and Muckleshoot tribes' Usual and Accustomed (U&A) fishing grounds; consequently, they reserved their rights under federal treaties to harvest salmon in commercial quantities from this area and use the waterway for a ceremonial and subsistence fishery.

The EW is used by the tribes as a resource and for cultural purposes. Currently, the Suquamish and Muckleshoot Tribes conduct a commercial netfishery in EW for salmon. Tribal fishermen can also engage in clamming activities (by means of boat access) in all intertidal areas of the EW (Figure 2-11), as well as subtidally for geoducks (currently geoducks are not being harvested from the EW).

Individuals other than tribal members are known to collect fish and crab from EW despite existing fish advisories. Although there are currently fish advisories posted (no consumption is advised for resident seafood, limits are advised for certain salmon species,[8] and no limits are posted for squid), fishing and crabbing are conducted from the north side of the Spokane Street Bridge, especially during summer and fall salmon runs and seasonal squid migration into Elliott Bay. Fishing has also been observed north of the eastern side of the Spokane

[8] Advisories for salmon are the same as those for Puget Sound.

Street Bridge from the riprap slopes during summer salmon runs. The potential clamming area for the general public is small because there are only two places where the public can gain access to intertidal areas of the EW (Figure 2-11). It is unknown if the general public is currently harvesting clams.

The EW is not a major area for recreational use compared to other waterbodies in and around Seattle (King County 1999). Recreational boating in the EW occurs on a limited basis. No boat ramps are present in the EW, but water access is provided at Jack Perry Memorial Shoreline Public Access (on the eastern side of the EW, south of Slip 36) for kayakers and other hand-launched non-motorized watercraft (e.g., canoes or rafts). Harbor Island Marina moorages in the EW are mostly used for commercial boats, but small recreational boats may enter from the LDW. The presence of the Spokane Street Bridge and the Railroad Bridge prohibit most boat passage, except at low tide by small, shallow-draft boats (e.g., kayaks and skiffs).

Few data have been located quantifying the frequency with which people use the EW for recreational purposes other than fishing. Few people, if any, engage in water activities such as swimming or scuba diving within the EW. Such uses are likely to continue to be limited by the active commercial use of the EW, the very limited public access due to security requirements of container terminals and the USCG facility, and the availability of nearby areas that provide superior recreational opportunities.

2.9.4 Ecological Habitats and Biological Communities

2.9.4.1 Habitat Types

Dredging and development since the early 1900s have substantially altered nearshore environments in Elliott Bay and the Green/Duwamish River. Prior to the channelization and industrialization of the Duwamish River, the habitat associated with the river's mouth was predominantly an intertidal/shallow subtidal estuarine mudflat. Since the creation of Harbor Island, all of the original habitat in the area that is now the EW has been either filled or dredged and channelized. There are no remaining tidal marsh or expansive mudflat areas within the EW.

The aquatic habitats in the EW include the water column and intertidal and subtidal substrates (typically mud, sand, gravel, cobble, or riprap). The habitat within EW is predominately deep water habitat with relatively little shallow subtidal and intertidal habitat, which is found primarily in the Junction/Sill reach, within Slip 27, and south of Slip 36 (approximately 6 acres have been identified as intertidal areas).

Shoreline armoring is present throughout the upper intertidal zone, but a few isolated areas of sloping mud and sand flats and gravel/cobble exist in the lower intertidal zone. Most of the intertidal sediment areas are along the eastern shoreline of the EW. Along the western shore, intertidal sediment is limited to small areas under the bridges. Gravel and cobble are the dominant matrices in the exposed intertidal areas. In addition, overwater structures, which are common throughout the EW, shade shallow water and intertidal habitats and inhibit the growth of plant communities (Battelle et al. 2001).

Areas within the EW that have been restored or may be restored in the future to enhance habitat conditions are listed below:

- In the Junction Reach, habitat restoration was conducted in 1989 with the creation of a shallow bench along the eastern shoreline at T-104, which was constructed of clean fine-grained substrate and provides valuable shallow water habitat for juvenile migratory fish and intertidal areas for clams.
- In the Sill Reach, habitat restoration is anticipated to be conducted by Bluefield Holdings, Inc. for the west side of the EW under the West Seattle Bridge, which would provide off-channel mudflat and marsh habitat, along with riparian vegetation. The restoration project would also involve removal of debris and creosote structures from the shoreline areas. The restoration is subject to Natural Resource Damage Trustee approval, EPA coordination, and obtaining permitting from federal, state, and City agencies. Construction timing is unknown.
- Just north of the Spokane Street Bridge, a mound of fill stabilized by rock was placed specifically for habitat restoration purposes. This mound provides shallow water and intertidal habitat.
- The bank along the southern part of Slip 27 has been replanted in an effort to restore natural habitat conditions to this area. The restoration extends from the top of bank (18.5 feet MLLW) down to 12 feet MLLW.

- Jack Perry Park is a 1.1-acre park located north of T-30 and south of the USCG facility. It provides 120 feet of intertidal area and shoreline access for public recreational activities and, as such, provides an area for potential future habitat enhancements.

2.9.4.2 Biological Communities

Dredging and development over the past 100 years have substantially altered nearshore environments in Elliott Bay and the Duwamish River estuary. Currently there is no natural shoreline in the EW. The aquatic habitats found in the EW are intertidal and subtidal, and water column habitats. Numerous infaunal and epibenthic invertebrate species inhabit the intertidal and subtidal substrates of the EW. Larger invertebrates also inhabit the EW, including crabs (Dungeness crabs [*Cancer magister*], red rock crabs [*Cancer productus*], graceful crabs [*Cancer gracilis*]), arthropods, and echinoderms.

Clam surveys were conducted at 11 intertidal areas (Windward 2010b); five of these areas were located in the southern narrow portion of the EW, three were located in and near Slip 27, and three were located along the shoreline south of Slip 36 (Figure 2-11). Nine of these intertidal areas contained suitable habitat for clams in the EW. During this survey, Macoma clams (*Macoma* spp.) were the most frequently observed species, followed by Japanese littleneck clams (*Venerupis philippinarum*) and butter clams (*Saxidomus gigantean*). Cockles (*Clinocardium nuttali*) and Eastern soft-shell clams (*Mya arenaria*) were observed only in the southern-most portion of the EW, under the bridges and along the restoration bench, respectively. Mussels were present wherever suitable substrate was present, primarily on pilings and sheetpile walls, based on a July 2008 survey. Geoducks are also present in deeper water in the northern part of the EW (Windward 2010c).

Diverse populations of fish, including 42 anadromous and resident fish species, also reside in or use the EW as a migration corridor. Salmon use the Duwamish River for rearing of juveniles and as a migration corridor for adults and juveniles. Adult salmon found in the LDW and EW spawn mainly in the middle reaches of the Green River and its tributaries (Grette and Salo 1986). Five species of juvenile salmon (Chinook [*Oncorhynchus tshawytscha*], chum [*Oncorhynchus keta*], coho [*Oncorhynchus kisutch*], pink

[*Oncorhynchus gorbuscha*], and steelhead [*Oncorhynchus mykiss*]) have been documented in the EW. Juvenile chum and Chinook salmon were the most abundant salmonid species captured in Slip 27 (Taylor Associates 2004; Shannon 2006; Windward 2010d). Sockeye salmon have been found upstream in the LDW (Kerwin and Nelson 2000). Juvenile salmon are expected to primarily feed in suitable nearshore habitats.

Of non-salmonid fish, English sole (*Parophrys vetulus*), Pacific herring (*Clupea pallasi*), Pacific staghorn sculpin(*Leptocottus armatus*), Pacific tomcod (*Microgadus proximus*), rock sole (*Lepidopsetta bilineata*), sand sole (*Psettichthys melanostictus*), shiner surfperch (*Cymatogaster aggregate*), sanddab species *(Citharichthys spp*), starry flounder (*Platichthys stellatus*), surf smelt (*Hypomesus pretiosus*), and three-spine stickleback (*Gasterosteus aculeatus*) are at least seasonally abundant in the EW.

There is very little information on bird and mammal populations in the vicinity of the EW; however, the relatively large home ranges associated with many bird and mammal species make the LDW data relevant to the EW. The LDW habitats support a diversity of wildlife species. Previous studies have reported 87 species of birds, 3 species of marine mammals, and 3 species of aquatic-dependent terrestrial mammals that use the LDW at least part of the year to feed, rest, or reproduce (Windward 2007a).

Sixteen aquatic and aquatic-dependent species reported in the vicinity of Elliott Bay area are listed under either the Endangered Species Act or by the Washington Department of Fish and Wildlife as candidate species, threatened species, endangered species, or species of concern. Of these species, Chinook salmon, coho salmon, steelhead salmon, brown rockfish (*Sebastes auriculatus*), bald eagle (*Haliaeetus leucocephalus*), western grebe (*Aechmophorus occidentalis*), and Pacific herring are commonly observed in the EW.

2.10 EW Baseline Dataset

Environmental investigations conducted within the EW, primarily in support of the SRI and dredging activities, have included the collection of surface sediment, subsurface sediment, fish, shellfish, benthic invertebrate tissue, surface water, and porewater samples for chemical analysis. This baseline dataset was used to support analyses in the SRI, including the ERA, the HHRA, the nature and extent evaluation, and the development of sediment RBTCs for human health and ecological receptors of concern. Eight surface sediment samples collected from Slip 36 within the EW in November 2014 (Amec Foster Wheeler 2015) were added to the SRI baseline dataset for the FS evaluation.[9] Additional data are also included in Appendix J for the purposes of recontamination evaluation (e.g., EW SD and CSO solids source control datasets, atmospheric deposition, and groundwater) and comparison to background. For the FS, the sediment data needed to support the design of remedial alternatives are the primary data used. The various components of data that make up the FS dataset are detailed below.

2.10.1 Surface Sediment

The surface sediment baseline dataset consists of 334 individual surface sediment samples from the EW SRI dataset, plus an additional 8 surface sediment samples collected in 2014 (342 total). The majority of the surface samples were collected for the purpose of site-wide characterization in 1996, 2002, and 2010; the dataset is well distributed spatially and representative of the site as a whole.

The intertidal sediment has been less frequently sampled, in part because there are few intertidal areas in EW. Multi-increment sampling (MIS) samples were collected to characterize the intertidal sediment for the risk assessments. The MIS samples consisted of four composite samples that were created from a total of 138 discrete surface sediment samples collected throughout the intertidal areas of the EW, each composite sample was created by combining approximately 30 unique sediment samples collected throughout the EW intertidal area. However, the MIS dataset is not being used in the FS since the four sample areas (encompassing all intertidal areas with clams) were composited specifically to evaluate HHRA direct contact clamming exposure scenarios, and not for remedial alternative evaluation.

In addition to the four intertidal MIS composite samples, polycyclic aromatic hydrocarbons (PAHs) were also analyzed as 15 different intertidal area composite samples (each of these

[9] These locations were sampled after the risk assessments (Windward 2012a, 2012b), initial EW FS modeling work, and source and pathway characterization data cutoff of August 2010. However, they are included in the statistical summaries of contamination in Section 2 and have been used to expand the remediation footprint in Section 6.

areas was part of an MIS sample composite area) created to characterize carcinogenic polycyclic aromatic hydrocarbons (cPAHs) in each intertidal sampling area (see Section 4.2.6.1 of the SRI; Windward and Anchor QEA 2014). cPAHs were further evaluated in the 15 intertidal composite samples because one of the three area-wide intertidal MIS replicate samples contained substantially higher concentrations of cPAHs than the other two area-wide MIS samples and had higher cPAH concentrations than the public access intertidal MIS composite sediment sample. This variance suggested that one or more sediment grab samples within the MIS composite contained elevated cPAH concentrations relative to the grab samples that went into the other replicate MIS samples. To identify the area with elevated cPAH concentrations, sediment volume from discrete sampling points used to create the MIS samples were combined by geographic subarea to create 15 intertidal composites to represent the nature and extent of cPAH contamination in the beach areas (see SRI Map 4-27).

Subtidal composite samples were created for 13 areas for the analysis of dioxins/furans and PCB congeners (see Figure 2-18). The intertidal area PAH samples and subtidal composites dioxin/furan samples, along with surface sediment grab samples, are used in this FS.

2.10.2 Subsurface Sediment

The baseline dataset includes 346 subsurface samples from 146 cores. A total of 214 samples (from 67 cores) were collected during site-wide investigations, including the SRI subsurface sediment sampling in 2010. The remaining 132 samples (from 79 cores) were collected to characterize sediment quality in potential dredging areas that were ultimately not dredged. Because the majority of the data were collected for the purpose of site-wide characterization, the dataset is well distributed spatially and representative of the site as a whole.

2.10.3 Phase 1 Dredge Area

The Phase 1 dredge area within the EW (see Figure 2-21), has four sets of surface sediment (0 to 10 cm) chemistry data (collected in 2005, 2006, 2007, and 2008). The Phase 1 dredge area was dredged between 2004 and 2005 and was then covered with a 1-foot-thick layer of sand cover material (March 1 to 15, 2005) and subsequently monitored annually for 3 years.

After initial dredging was completed, post-dredge samples were collected in January 2005 to determine if additional dredging was needed in locations where sediment concentrations were not substantially reduced. After completion of additional dredging in select areas, pre-sand placement (i.e., post-dredge) sediment samples were collected in February 2005 and analyzed for the analytes that exceeded sediment quality standards (SQS) in the January 2005 post-dredge surface (metals, semivolatile organic compounds [SVOCs], and PCBs), so the concentrations of analytes that exceeded the SQS in sediment remaining in place would be known.

A sand layer was then placed to meet Ecology's anti-degradation policy requirements and to not leave a contaminated surface exposed. The thickness measured after placement ranged from 6 inches to more than 1 foot and averaged 10 inches (Anchor and Windward 2005), and since that time several years of new material has deposited. After placement of the sand, subsequent surface sediment quality monitoring was conducted for 3 years (2006 to 2008) to evaluate the integrity of the sand layer and monitor potential recontamination.

Consistent with the SRI, the FS uses data from the pre-sand placement (February 2005)[10] and subsequent post-sand placement monitoring events (2006 to 2008)[11] to define areas requiring remediation. These dredging and sand placement activities were used to inform technology application assumptions that would be employed in the EW (Sections 7 and 8). In addition, observations from these monitoring events were used to inform methods for estimating post-cover concentrations used in modeling (Appendix B, Part 3A).

2.10.4 Other Datasets Used in the FS

Several other datasets were used to characterize the contaminant concentrations associated with upstream inputs from LDW lateral and sediment bed concentrations and Green River sources. The EW uses the same datasets as the LDW to characterize the contaminant concentrations associated with LDW lateral inputs (e.g., SDs and CSOs) and Green River

[10] The pre-sand placement sediment data from 2005 are provided in the SRI (Windward and Anchor QEA 2014) and are treated as shallow subsurface sediment because the sediments are currently covered by sand cover material with a minimum thickness of 6 inches.

[11] Only most recent post-sand placement monitoring results were used for co-located samples.

upstream inputs, except one new core collected in 2010 from the Turning Basin for dredged material characterization was added to the dataset (see Section 7 of the SRI; Windward and Anchor QEA 2014). Datasets used to characterize Green River inputs include cores collected in the most upstream portion of the LDW navigation channel and upper turning basin, surface sediment samples and solids from centrifuged water samples collected upstream of the LDW (many collected by Ecology), and whole-water samples collected by the County upstream of the LDW. All of these datasets are discussed in Appendix C, Part 3 of the LDW FS (AECOM 2012). The LDW sediment bed concentrations were based on LDW surface sediment summaries presented in the LDW FS (AECOM 2012).

Natural background concentrations of certain contaminants were estimated for use in developing PRGs (Section 4.3.3) and the recontamination evaluation (Section 5). Natural background concentrations were estimated from a statistical evaluation of surface sediment data collected from non-urban areas in Puget Sound. The Dredged Material Management Program (DMMP) agencies collected these data in 2008 during the Puget Sound sediment Ocean Survey Vessel (OSV) *Bold* Summer 2008 Survey (OSV *Bold* Survey; DMMP 2009). These data are discussed in Section 4 for the development of PRGs. Appendix B estimates sediment concentrations entering the EW using upstream contributions (Green River and LDW) and EW lateral inputs. The upstream contributions and lateral input data are further evaluated in Section 5 and are used to estimate net incoming solids concentrations for the purposes of the recontamination evaluation. In addition, the upstream contributions and lateral inputs are used in Appendix A to evaluate the technical possibility of achieving natural background-based PRGs.

2.10.5 Tissue

Tissue samples of many different fish and invertebrate species have been collected and analyzed. Tissue data included samples of English sole, shiner surfperch, brown rockfish, juvenile Chinook salmon, red rock and Dungeness crabs, intertidal clams (i.e., butter, little neck, cockles, and Eastern soft-shell), mussels, geoducks, shrimp, and small benthic invertebrates that live in or on the sediment, such as amphipods and marine worms. These species were selected because they were either known or assumed to be representative of species that could be consumed by people, fish, or aquatic-dependent wildlife within the EW or they were identified as important ecological receptors of concern. Their tissues were analyzed for a wide variety of contaminants. Tissue data were used to evaluate risks to human health and ecological receptors in the HHRA (Windward 2012b) and ERA (Windward 2012a), respectively. The PRGs in this FS are developed to reduce the risks to people who consume seafood from the waterway or come into contact with EW sediments and water and ecological receptors that live or forage within the waterway.

2.10.6 Water

PCB surface water data were used in food web modeling, which was used in developing RBTCs between tissues and sediments. Other surface water data were not used in development of RBTCs. Surface water data can be used during evaluation of site conditions compared to state water quality standards, an ARAR for the sediment cleanup.

Contaminant concentrations in surface water and porewater were also summarized in the SRI (Windward and Anchor QEA 2014). A large number of surface water grab samples were collected along a transect in the EW (at Station 4950) by King County between October 1996 and June 1997 and analyzed for conventional parameters, metals, and SVOCs. Surface water sampling was also conducted in 2008 and 2009 as part of the SRI. Samples were collected from five locations throughout the EW during the wet season, the dry season, and a large storm event. These samples were analyzed for conventional parameters, metals, SVOCs, and PCB congeners. SVOCs were not detected in the King County samples. Improved sensitivity in the analyses resulted in higher detection frequencies for SVOCs in the SRI dataset.

Porewater data were collected from subtidal surface and subsurface sediments for the analysis of tributyltin (TBT) primarily in samples collected for dredge material characterization and post-dredge monitoring studies. TBT was detected in 83 out of 99 samples. In addition, 13 porewater samples were collected from two intertidal areas for the analysis of volatile organic compounds (VOCs). Naphthalene was detected in two samples, benzene was detected in two samples, and cis-1,2-dichloroethene was detected in one sample.

2.11 Conceptual Site Model

2.11.1 Physical Conceptual Site Model

The physical CSM focuses on the important processes that affect hydrodynamic and sediment transport processes in the EW. Information used to develop the physical CSM included site-specific empirical data and output from hydrodynamic, sediment deposition, and propeller wash (propwash) modeling, as presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012) and summarized in the SRI (Windward and Anchor QEA 2014). Empirical data collected as part of this work include tidal elevations from Elliott Bay and the EW, flow data from the Green River, velocity and salinity profile measurements south and north of the Spokane Street Corridor and within the main body of the EW, sedimentation data from the EW, and in situ measurements of critical shear stress in the EW. Model output included predictions of current velocities, salinities, and suspended solids for average and high-flow events within the EW (hydrodynamic model), predictions of annual average initial deposition patterns from lateral sources within the EW (particle tracking model [PTM]), and near-bottom current velocities due to vessel operations (from propwash) within the EW. Figure 2-12 presents a graphical summary of the sediment transport processes within the EW.

Hydrodynamic circulation in the EW is controlled by tidal exchange with Elliott Bay to the north and freshwater inflow from the Green River (through the LDW). Stormwater and CSO inflows from the directly contributing drainage basins have a negligible influence on large-scale circulation in the EW. Water circulation in the EW can be generally described as two-layer flow, with saltwater extending from Elliott Bay upstream through the EW and into the LDW underneath a thin layer of fresher water flowing from the Green/Duwamish River system (Figure 2-12). In general, as upstream inflow increases, predicted surface velocities within the EW increase. Average surface velocities range from 20 to 25 centimeters per second (cm/s), and maximum surface velocities range from 90 to 95 cm/s (2- to 100-year flows, respectively). Average and maximum predicted surface velocities at mean annual flow are 10 and 70 cm/s, respectively. Predicted average near-bed velocities are relatively constant over the range of flows from mean annual to the 100-year upstream flow at 5 cm/s. Maximum near-bed velocities increase with increasing upstream flow; from 18 to 28 cm/s for mean annual and 100-year flows, respectively.

The vertical gradient in salinity in the EW is directly related to upstream flow into the EW, with the range in salinity between surface water and bottom water increasing with increasing upstream flow. However, the majority of the water column remains saline even under the 100-year flow conditions (as predicted by the hydrodynamic model). The split in flow between the EW and WW is predicted from modeling to be about equal during normal flow events (annual average) but approximately 30%:70% (EW:WW) during 2-year flows and higher events. The split in flow was validated over a range of tidal conditions during a higher flow event (4,000 cubic feet per second [cfs]) using Acoustic Doppler Current Profiler (ADCP) transect data collected within the EW as part of the sediment transport evaluation (STE).

Sediment sources to the EW include the upstream sources (Green River, LDW bed and bank sediments, and LDW lateral load sediments), downstream sources (Elliott Bay), and local sources (lateral sources that drain directly to the EW). An evaluation of 18 geochronology cores recovered within the EW suggests that the majority of the Shallow Main Body Reach (between Stations 5000 and 6800) and the interior of Slip 27 (Figure 2-1) are net depositional. Net sedimentation rates for these areas range from 0.2 to greater than 2.0 centimeters per year (cm/yr). The Deep Main Body Reach (Stations 0 to 5000), including the mouth of Slip 36, appears to be net depositional but influenced by episodic erosion events due to propwash from vessel operations. Prop wash mixing events may also result in episodic scour of naturally deposited sediments in some areas of the Deep Main Body Reach, and therefore, long-term net sedimentation is functionally zero. Consistent with patterns of changes in bathymetric elevations within the waterway, some of the sediment mobilized during vessel scour events is deposited in adjacent areas within the EW. The extent of areas with functional zero net sedimentation was not quantified. Geochronology cores were not retrieved in the Sill and Junction Reaches due to consolidated sand and gravel surface sediments at proposed sampling locations in these areas. Therefore, net sedimentation rates could not be quantified for the Sill or Junction Reaches. This result suggests that the Sill and Junction Reaches may not be net depositional in some areas. The extent of areas with no net deposition was not quantified.

Results of the sediment transport modeling completed for the LDW (QEA 2008) and results of the PTM for initial deposition of lateral sources within the EW completed for this FS suggest that 99% of the sediment load entering the EW is from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral loads), and less than 0.3% is from lateral loads within the EW itself (Anchor QEA and Coast & Harbor Engineering 2012). Results from the LDW sediment transport model (QEA 2008) suggest that essentially 100% of the incoming upstream load to the EW from the Green River and LDW (bed sediments and lateral loads) consist of silts and clays. Sediment load into the EW from Elliott Bay is assumed to be negligible compared to the other sources. A comparison of predicted estimates of sediment loads and average net sedimentation rates in the EW (measured from geochronology cores) indicates that 25% to 60% of the incoming sediment load is estimated to deposit in the EW (capture efficiency) and 40% to 75% of the incoming load is estimated to leave the EW. Initial mass deposition patterns within the EW from local lateral sources (evaluated through PTM) show the majority of initial deposition occurs close to the outfall locations, with relatively little deposition (less than 0.2 cm/yr) compared to the average net sedimentation rates in the EW (Figure 2-14). Contaminants associated with various sediment sources are presented in Section 5.

As presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012), riverine and tidal currents in the EW are not expected to cause significant erosion of in situ bed sediments, as the maximum predicted bed shear stress during a 100-year high-flow event modeled to be less than the mean critical shear stress[12] of the bed sediments (estimated from site-specific SEDflume data). Modeled bed shear stress due to large vessel operations (e.g., propwash) in portions of the Deep Main Body Reach (north of Station 4200) is significantly greater than bed shear stress due to natural forces and is regularly above the critical shear stress for bedded sediments. Consequently, these areas are likely subject to episodic erosion and re-suspension of bed sediments due to propwash. The remainder of the Deep Main Body Reach (between Stations 4200 and 4900), the Shallow Main Body Reach, and the Junction Reach are also subject to impacts from vessel operations; however, the vessels that operate in these areas are smaller in size and operate less frequently than in the Deep Main Body Reach (north of Station 4200). Therefore, these areas may be subject to occasional erosion or re-suspension of surface sediments due to propwash.

[12] In the STER (Anchor QEA and Coast & Harbor Engineering 2012) and SRI (Windward and Anchor QEA 2014), critical shear stress is defined as a property of the in situ bed sediments. It represents the value of shear stress (applied to that bed due to current velocities) at which the bed sediment would begin to mobilize (e.g., erode).

Information on vessel types and typical and extreme vessel operations during berthing and navigation with the EW were compiled in the STER (Anchor QEA and Coast & Harbor Engineering 2012) and SRI (Windward and Anchor QEA 2014). This information was used to develop operational areas within the EW where potential vessel operations were similar. These operational areas and the propwash evaluation are discussed in Section 5.

2.11.2 Chemical CSM (Nature and Extent of Contamination in Sediment)

Four risk driver COCs were identified in the HHRA for the EW based on risks associated with seafood consumption or direct sediment contact: total PCBs, arsenic, cPAHs, and dioxins/furans (see Section 3.2). Total PCBs and TBT were also identified in the ERA as risk driver COCs for fish and benthic invertebrates, respectively (see Section 3.1). In addition, 29 chemicals were identified as COCs for benthic invertebrates because detected concentrations of these 29 chemicals exceeded the SQS of the Washington State SMS at one or more locations. Total PCB concentrations and mercury concentrations in surface sediment exceeded the SQS at the greatest number of locations.

Tables 2-1 and 2-2 summarize minimum and maximum detections, average concentrations, and detection frequencies of human health and benthic risk drivers, respectively. Figures provided in this section and in subsequent sections of the FS use Thiessen polygons[13] to spatially represent results from specific point locations.[14] This method was selected rather than other interpolation methods due to the high density of samples collected from the EW, the relative lack of bias in sample locations, and for consistency with comparisons of point concentrations to SMS criteria and other point-based RALs. The distributions of risk driver COCs in sediment are discussed below and shown in Figures 2-15 through 2-20. Additional details on the nature and extent of contamination is presented in the SRI (Windward and Anchor QEA 2014); only summary level information is presented in the FS.

[13] All methods of estimation by interpolation have uncertainty, including interpolation by Thiessen polygon.

[14] Dioxins and furan TEQ and TBT concentrations are not represented on figures as Thiessen polygons, but as individual points due the smaller size of these datasets. During remedial design, additional samples may be collected and tested where dioxin and furan information is limited.

2.11.2.1 Surface Sediment Chemistry

Human Health Risk Drivers

Table 2-1 summarizes the concentrations in the EW for the four human health risk drivers: total PCB, cPAH, arsenic, and dioxin/furan toxic equivalent (TEQ). These results are presented in dry weight for consistency with the RBTCs developed in the SRI (Windward and Anchor QEA 2014). PCBs are widely distributed in surface sediment throughout the EW. Total PCBs were detected in 95% of the 248 surface sediment samples in which they were analyzed, at concentrations ranging from 6 to 8,400 µg/kg dw, with a mean concentration of 490 µg/kg dw and a SWAC of 460 µg/kg dw.

Table 2-1
Statistical Summaries for Human Health Risk Driver COCs in Surface Sediment

Contaminant	Unit	Detection Frequency	Concentration				SWAC
			Mean	Median	95th Percentile	Maximum	
Surface							
Total PCBs[a]	µg/kg dw	235/248	490	290	1,600	8,400	460
cPAHs[b]	µg TEQ/kg dw	15/15[c]	1,900	230	nc	17,000	680
		241/248	1,600	250	3,500	68,000	
Arsenic[d]	mg/kg dw	170/239	11	6.7	21	250	9.0
Dioxins/furans[e]	ng TEQ/kg dw	13/13[f]	16	16	nc	31	nc
		19/19[g]	32	38	52	71	
MIS composite samples[h]							
Total PCBs[a]	µg/kg dw	3/3[i]	970	770	nc	1,590	nc
		1/1[j]	nc	nc	nc	370	
cPAHs[b]	µg TEQ/kg dw	3/3[i]	1,000	780	nc	1,900	nc
		1/1[j]	nc	nc	nc	390	
Arsenic[d]	mg/kg dw	3/3[i]	10	9.1	nc	13.3	nc
		1/1[j]	nc	nc	nc	7.7	
Dioxins/furans[e]	ng TEQ/kg dw	3/3[i]	12.1	13.2	nc	13.8	nc
		1/1[j]	nc	nc	nc	8.52	
Subsurface							
Total PCBs[a]	µg/kg dw	207/290	1,500	275	4,300	17,600	nc
cPAHs[b]	µg TEQ/kg dw	218/269	1,000	250	3,600	23,000	nc
Arsenic[d]	mg/kg dw	250/255	10	9	29	96	nc
Dioxins/furans[e]	ng TEQ/kg dw	16/16	17.2	2.70	78.0	184	nc

Notes:

a. Total PCBs represent the sum of the detected concentrations of the individual Aroclors. If none of the individual Aroclors were detected in a given sample, the non-detect value represents the highest reporting limit.
b. Total cPAH TEQs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds. PEF values (California EPA 2005; Ecology 2001) are based on the individual PAH component's relative toxicity to benzo(a)pyrene. By using the PEFs, the toxicity of the various cPAH compounds can be expressed as a single number, the TEQ. If an individual PAH compound was not detected, the PEF for that compound was multiplied by one-half the RL for that compound.
c. Intertidal composite samples.
d. Summary statistics were calculated assuming one-half the reporting limit for non-detect results.
e. Dioxin/furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006). The TEF expresses the toxicity of dioxins/furans relative to the most toxic form of dioxin (2,3,7,8-TCDD). By using the TEFs, the toxicity of the various dioxin/furan congeners can be expressed as a single number, the TEQ. Dioxin/furan TEQs were calculated for each sample by summing the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener. In cases where the congener result was K-flagged or EMPC-flagged, the TEF for that congener was multiplied by one-half the reported value for that congener.
f. Subtidal surface composite samples collected in 13 subareas of the waterway.
g. Sediment grab samples selected for dioxin/furan analysis.
h. Intertidal composite samples collected using multi-increment sampling (MIS) technique.
i. Area-wide intertidal MIS composite.
j. Public access intertidal MIS composite.

µg – microgram
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
EMPC – estimated maximum possible concentration
kg – kilogram
MIS – multi-increment sampling
nc – not calculated
ng – nanogram
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
RL – reporting limit
SWAC – spatially-weighted average concentration
TEF – toxic equivalency factor
TEQ – toxic equivalent

At least one cPAH compound was detected in 97% of the 248 surface sediment grab samples, with concentrations ranging from 15 to 68,000 µg TEQ/kg dw, with a mean concentration of 1,600 µg TEQ/kg dw and a SWAC of 680 µg TEQ/kg dw (Table 2-1). In addition to the surface sediment grab samples, cPAHs were measured in four intertidal MIS composite samples (encompassing all intertidal areas with clams) and 15 intertidal composite samples (each of these were part of the MIS sampling area) created to characterize cPAHs in each intertidal sampling area (Figures 2-16a through 2-16c). cPAHs were detected in all 15 of the surface sediment intertidal composite samples, with concentrations ranging from 18 to 17,000 µg TEQ/kg dw (Table 2-1).

Arsenic was detected in 71% of the 239 surface sediment grab samples with a range of concentrations from 2.3 to 250 mg/kg dw with a mean concentration of 11.0, a 95th percentile of 21 mg/kg dw, and a SWAC of 9.0 mg/kg dw (Table 2-1 and Figures 2-17a through 2-17c).

Dioxins/furans were measured in subtidal composite sediment samples created for 13 subareas throughout the waterway and in four intertidal MIS composite sediment samples. Dioxins/furans were detected in all 13 subtidal composite samples with TEQ concentrations ranging from 4.0 to 31 nanograms (ng) TEQ/kg dw, and in all four intertidal MIS composite samples with concentrations ranging from 9.2 to 13.8 ng TEQ/kg dw. In addition, 19 individual surface sediment grab samples were analyzed for dioxins/furans. Dioxins/furans were detected in all 19 grab samples with TEQ concentrations ranging from 2.8 to 71 ng TEQ/kg dw (Table 2-1 and Figures 2-18a through 2-18c).

Benthic Risk Drivers

Table 2-2 presents a summary of chemicals detected in surface sediment samples relative to numerical chemical SMS criteria[15] to evaluate potential risk to benthic organisms. The SMS criteria uses two values: the SQS (WAC 173-204-320) and the cleanup screening level (CSL) (WAC 173-204-562). The SQS criteria represent numerical chemical concentrations below which sediment is designated as having no adverse effect on biological resources. The CSL criteria represent chemical concentrations at which minor adverse effects on biological resources are expected to occur. At chemical concentrations above the SQS but below the CSL, sediment is designated as having the potential for minor adverse effect on biological resources. To facilitate the evaluation of SMS exceedances, Table 2-2 presents an exceedance factor, which is the ratio of the maximum detected concentration of a chemical to either the SQS or CSL criteria.

In surface sediment, 175 locations (out of 251) had one or more exceedance of the chemical SQS. Detected total PCBs most frequently (65%) exceeded its SQS or CSL criterion, followed

[15] Many of the SMS criteria are in units normalized to the organic carbon (OC) content in the sediment sample (e.g., mg/kg OC) because the carbon content can affect the bioavailability or toxicity of nonpolar or nonionizable organic chemicals to benthic organisms. OC-normalization is not considered to be appropriate for TOC concentrations ≤ 0.5% or ≥ 4.0%. In these cases, dry weight chemical concentrations were compared with the lowest apparent effects threshold (LAET), which is functionally equivalent to the SQS, or the second lowest AET (2LAET), which is functionally equivalent to the CSL.

by mercury (21%) and 1,4-dichlorobenzene (13%). All other detected chemicals exceeded their respective SQS or CSL criteria in less than 10% of the samples.

Twenty-four contaminants exceeded their respective CSL in at least one sample, with total PCBs being the most frequently detected above its CSL criterion (23 of 248 locations, or 9.3%) followed by acenaphthene (13 of 248 locations, or 5.2%) and mercury (10 of 247 locations, or 4.0%); all other contaminants were detected above their respective CSL criterion in less than 4% of the samples.

The SMS also include biological criteria (WAC 173-204-315) based on sediment toxicity tests and benthic infauna abundance. Because apparent effects thresholds (AETs), which form the basis for the SMS chemical criteria, are based on sediment samples with a mixture of chemicals from various locations in Puget Sound and the exceedance of the SMS chemical criteria is not always an accurate predictor of adverse effects, the regulations state that site-specific biological tests (sediment toxicity tests and the assessment of benthic infauna abundances) may be conducted to provide confirmation that site-specific chemistry data indicate a hazard to benthic invertebrate communities. According to the state regulations, the tested sediments are designated as exceeding the SQS if the SQS biological criteria are exceeded for any one of the three toxicity tests conducted for a sampling location. Likewise, sediments are designated as exceeding the CSL if the CSL biological criteria are exceeded for any one of the three toxicity tests, or if the SQS biological effects criteria are exceeded in any two of the three toxicity tests conducted for a sampling location (WAC 173-204-420(3)). The SQS and CSL designations based on biological criteria override the SQS and CSL designations based on chemistry results. For example, if a location has a chemical CSL exceedance but is tested and found not to exceed the biological SQS criterion, it is not categorized as an SMS exceedance.

Table 2-2
Statistical Summaries for Benthic Risk Driver COCs in Surface Sediment

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. Non-detected with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. Non-detected with RL > CSL	
Metals										
Arsenic	170/239	71	0/239	0.0	0	4.4	3/239	1.3	0	2.7
Cadmium	163/239	68	1/239	0.4	0	1.3	1/239	0.4	0	1.0
Mercury	241/247	98	41/247	17	0	2.6	10/247	4.0	0	1.8
Zinc	239/239	100	4/239	1.7	0	3.2	2/239	0.8	0	1.4
PAHs										
2-Methylnaphthalene	95/248	38	0/248	0.0	0	2.2	3/248	1.2	0	1.3
Acenaphthene	134/248	54	11/248	4.4	0	53.1	13/248	5.2	0	38.0
Anthracene	217/248	88	5/248	2.0	0	19.8	2/248	0.8	0	19.8
Benzo(a)anthracene	234/248	94	7/248	2.8	0	31.5	7/248	2.8	0	25.6
Benzo(a)pyrene	233/248	94	7/248	2.8	0	27.5	8/248	3.2	0	27.5
Total benzofluoranthenes[e]	236/248	95	7/248	2.8	0	21.3	8/248	3.2	0	18.9
Chrysene	238/248	96	9/248	3.6	0	32.1	3/248	1.2	0	16.1
Dibenzofuran	115/248	46	9/248	3.6	0	17.8	6/248	2.4	0	6.3
Fluoranthene	241/248	97	15/248	6.0	0	46.5	7/248	2.8	0	31.6
Fluorene	152/248	61	10/248	4.0	0	21.1	9/248	3.6	0	16.1
Phenanthrene	238/248	96	14/248	5.6	0	37.3	9/248	3.6	0	37.3
Pyrene	243/248	98	2/248	0.8	0	31.9	5/248	2.0	0	25.2
Total HPAHs[g]	245/248	99	10/248	4.0	0	34.1	7/248	2.8	0	24.1

Table 2-2
Statistical Summaries for Benthic Risk Driver COCs in Surface Sediment

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. Non-detected with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. Non-detected with RL > CSL	
Total LPAHs[h]	238/248	96	6/248	2.4	0	20.0	9/248	3.6	0	20.0
Phthalates										
BEHP	215/239	90	4/239	1.7	1	40.0	5/239	2.1	1	24.0
Benzylbutyl phthalate	109/239	46	16/239	6.7	6	3.8	0/239	0.0	0	0.3
Di-n-butyl phthalate	33/239	14	0/239	0.0	0	12.0	1/239	0.4	0	1.5
Other SVOCs										
1,4-Dichlorobenzene	153/239	64	21/239	8.8	2	350.0	9/239	3.8	0	120.0
2,4-Dimethylphenol	19/239	8	0/239	0.0	0	3.8	9/239	3.8	39	3.8
n-Nitrosodiphenylamine	2/239	1	0/239	0.0	0	6.4	3/239	1.3	2	4.5
PCBs										
Total PCBs	235/248	95	137/248	55	0	70.0	23/248	9.3	0	13.0
TBTs										
TBT[k]	68/75	91	11/75	15	0	50.0	NA	NA	NA	NA

Notes:
a. Represents the number of detects per total number of samples.
b. Represents the number of detects > SQS and ≤ CSL per total number of samples. If any individual sample had a TOC content > 4% or < 0.5% and the dry-weight concentration was > LAET and ≤ 2LAET, the concentration was considered to be > SQS and ≤ CSL.
c. Represents the number of detects > CSL per the total number of samples. If any individual location had a TOC content > 4% or < 0.5% and the dry-weight concentration was > 2LAET, the concentration was considered to be > CSL.
d. One of these six samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.

e. Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.
f. One of these three samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.
g. Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.
h. Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.
i. This sample could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.
j. Two of these twenty-three samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.
k. TBT does not have SMS criteria; however, the ecological risk assessment (Windward 2012a) calculated a RBTC of 7.5 mg/kg OC for benthic invertebrates. This RBTC value was used as a surrogate for the frequency of detected concentrations above the SQS column.

2LAET – second-lowest-apparent-effect threshold
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredged Material Management Program
dw – dry weight
EF – exceedance factor
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LAET – lowest-apparent-effect threshold
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligram per kilogram
NA – not applicable
OC – organic carbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RL – reporting limit
SRI – Supplemental Remedial Investigation
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SVOC – semivolatile organic compound
TBT – tributyltin
TOC – total organic carbon

Thiessen polygons were used to estimate the areal extent of potential benthic effects based on combined toxicity test results and surface sediment chemistry data. The maximum exceedance factor for individual SMS contaminants at each station was used to assign a status to that station's Thiessen polygon. Using the final SMS designation based on both sediment chemistry and toxicity test results, approximately 39% of the EW is designated as having no adverse effects to benthic community (all less than SQS), while approximately 23% are expected to have minor adverse effects (greater than or equal to CSL). Approximately 38% of the area was between the SQS and the CSL and is generally interpreted as having a potential for minor adverse effects on the benthic community.[16] Figures 2-20a through 2-20c show the final designation of each area, as represented by Thiessen polygon, according to SMS rules.

2.11.2.2 Subsurface Sediment Chemistry

In general, elevated subsurface contaminant concentrations were co-located with areas of elevated surface sediment concentrations. However, there were areas with subsurface sediment concentrations that exceeded the surface sediment concentrations. Slip 27 had generally higher subsurface sediment contaminant concentrations compared to the surface sediment concentrations and the shallow main body area had higher subsurface sediment concentrations of total PCBs and mercury relative to the surface sediment concentrations of these contaminants in that area. The analysis of vertical patterns of chemicals in subsurface sediment showed that elevated contaminant concentrations were mostly detected in deeper core intervals in areas that have not been dredged since the 1960s.

Overall, 95% of the cores collected from the EW during SRI sampling events had contaminant concentrations that were less than the SQS in the lowest interval of the core that was analyzed (Figures 2-20a through 2-20c). In the cores where the lower alluvium was analyzed (74% of the cores), only three locations had SQS exceedances in that zone (Figures 2-20a though 2-20c); however, the exceedances at depth at these locations were likely due to inclusion of transitional or contact layer material from the upper unit.

[16] As noted in Section 2.10.1, these values differ slightly from those presented in the EW SRI (Windward and Anchor QEA 2014) due to inclusion of Slip 36 data collected in 2014.

2.11.2.3 Sediment Chemistry in Phase 1 Dredge Area

The Phase 1 dredge area was sampled following completion of initial dredging (February 1, 2005), immediately after a second partial dredging (February 3 to 25, 2005), and following placement of a 1-foot-thick layer of sand cover material (March 1 to 15, 2005). Pre-sand placement sediment samples were collected following the removal of the additional foot of sediment and were analyzed for the analytes that exceeded the SMS in the post-dredge surface (metals, mercury, SVOCs, and PCBs). Mercury and total PCBs were the contaminants that exceeded the SQS and CSL in the greatest number of samples. The current surface, pre-sand placement surface, and subsurface chemistry relative to SMS exceedances are presented on Figure 2-21.

The current Phase 1 dredge area surface sediment dataset consists of post-sand placement data collected for recontamination monitoring in 2006, 2007, and 2008. The pre-sand placement surface sediment dataset is still valid, but considered subsurface sediment because the area is covered with at least 6 inches of sand cover material. Therefore, both the pre-sand and post-sand placement results are considered to establish the area of active remediation discussed in Section 6 and used together to represent sediment conditions in the clean sand placement areas of the Phase 1 dredge area on the figures presented in Section 6 to determine the extent of removal areas.

In the SRI (Windward and Anchor QEA 2014), the SQS exceedances for the current surface sediment data were compared with the surface sediment data prior to the placement of sand cover material (i.e., pre-sand placement sediment). The current surface sediment has fewer exceedances of the CSL than were seen in the pre-sand placement samples. The six locations with CSL exceedances in the current sediment surface are associated with surface sediment concentrations of total PCBs, 1,4-dichlorobenzene, and bis(2-ethylhexyl) phthalate (BEHP). These locations were not spatially associated with SMS exceedances for 1,4-dichlorobenzene or BEHP in the pre-sand placement sediment sampling. However, SMS exceedances for total PCBs were observed in pre-sand placement locations near two locations (EW-RM-34 and EW-RM-32) that exceed the SQS and CSL for total PCBs, respectively (Figure 2-21).

2.11.3 Sources and Pathways

After the physical and chemical settings are described, the third component of a CSM evaluates the source of the contaminants and the likely pathways by which these contaminants are transported into and within the EW.

2.11.3.1 Historical and Ongoing Chemical Contaminants and Sources

Today, many sources of historical origin, including direct discharges of municipal and industrial wastewater and spills, have been identified and controlled. These controls have been implemented by enhanced regulatory requirements, improved housekeeping practices, and technological advances. Further discussion of historical chemical contaminants is included in Section 9.2 of the SRI (Windward and Anchor QEA 2014).

2.11.3.2 Potential Ongoing Source Pathways

Potential sources of contaminants to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the EW through various pathways. The completeness of the pathways with respect to the transport of COCs and the evaluation of potential sources are summarized in this section and detailed in the SRI (Windward and Anchor QEA 2014). The potential ongoing sources and pathways to the EW include the following:

- Direct discharge into the EW (e.g., CSOs, stormwater, or sheetflow from properties immediately adjacent to the waterway)
- Groundwater discharge (including tidally influenced groundwater discharge)
- Bank erosion
- Atmospheric deposition
- Spills and/or leaks to the ground, surface water, or directly into the EW (may be a potential source or pathway)
- Abrasion and leaching of treated-wood structures
- Surface water inputs and sediment transport

As described in Sections 3 and 9 of the SRI (Windward and Anchor QEA 2014), direct discharges and upstream inputs are pathways of the predominant sources of sediment inputs to the EW; therefore, those two pathways for sources are integrated into the STE presented in Section 5 of this FS. Both the sediment transport processes and source inputs are incorporated into the assessment of sediment recontamination potential for the remedial alternatives in Section 9.

Sources and pathways to the EW are subject to ongoing regulatory, permitting, and other source control programs as described in Section 2.12 and discussed in greater detail in Section 9.3 of the SRI (Windward and Anchor QEA 2014). These programs will continue to collect data following the completion of this FS. If necessary, additional findings will be incorporated into post-ROD site-specific remedial design as appropriate.

Direct Discharge

In general, direct discharge systems include municipal or other publicly owned drainage systems, privately owned and managed SDs, and sanitary/combined sewer systems. In addition to direct discharges, some small percentage of stormwater also enters the EW from adjacent properties via sheetflow. As described in the SRI, less than 0.3% of the solids input into the EW are from direct discharges from EW drainage basins. Solids inputs associated with direct discharges to the EW are evaluated in Section 5.

Stormwater is conveyed to the EW by SDs and CSO systems. SDs provide a complete pathway to the EW and include both public and private SD systems. (CSO systems are discussed below). The public SDs are owned and operated by the City or the Port and are covered under their respective National Pollutant Discharge Elimination System (NPDES) municipal stormwater permits and Port tenant industrial permits, where applicable. The USCG facility has coverage under a federal multi-sector general permit. All other drainage systems are classified as private (i.e., outfalls not owned by the Port, City, or USCG).

SDs collect urban runoff from roadways and other upland areas (e.g., commercial, industrial, and residential properties). Urban areas have the potential to accumulate particulate materials, dust, oil, asphalt, rust, rubber, metals, pesticides, detergents, and other chemicals resulting from urban activities and atmospheric deposition. Contaminants present on the ground (e.g., roadways, parking lots, residential yards, or industrial yard areas) can then be flushed into SDs during wet weather and transported to the EW in dissolved or particulate form. These drainage networks also provide a complete pathway for spills and leaks to reach the EW.

CSO discharges are a complete pathway for contaminants entering the EW. CSO events can occur during heavy rainfall when the CSO system capacity is insufficient to transport the volume of both sanitary wastewater and stormwater flows to the wastewater treatment plant. When this capacity is exceeded, excess flow is discharged to the EW through an overflow structure or relief point. CSOs consist of a combination of untreated municipal and industrial wastewater and stormwater runoff. Infrastructure improvements have greatly improved system storage capacity and reduced the number of discharges from CSO systems. Both the County and City have CSO control plans, which will greatly reduce inputs from CSOs in the future.

Sheetflow is a complete pathway where surface water runoff directly enters the EW from berth aprons, deck drains, bridges, and areas immediately adjacent to the EW during rain events. In areas lacking stormwater collection systems potential sources such as contaminated soils or contaminants improperly stored either as raw or as waste materials could be carried directly over these surfaces to the EW.

Upland cleanup sites are also located within EW SD and CSO drainage areas. These sites are of interest for EW sediment recontamination to the extent that they could potentially contribute to elevated contaminant levels in the EW due to lateral discharges that are included in the recontamination evaluation in Section 5.

Groundwater Discharge

Groundwater discharge from upland contaminated sites is a potentially complete pathway for transport of contaminants. Groundwater flow in the surrounding basin is generally toward the EW, although the direction varies locally depending on the nature of subsurface materials, hydrostratigraphy, and proximity to the EW. Near the EW, tidal action influences groundwater flow directions, rates, and water quality. Groundwater discharges into the EW through sediments and seeps observable on the embankment surface during low tide. The determination of whether a contaminant identified in groundwater will impact sediment or surface water quality was presented in the SRI (Section 9.4.4, Table 9-20, Figures 9-20 through 9-24, and Appendix J of Windward and Anchor QEA 2014) and briefly described below.

Extensive nearshore groundwater and seep information is available for nearshore cleanup sites to evaluate the potential for groundwater discharging to the EW to impact sediment quality (Appendix J of the SRI). These data were developed during previous investigation and cleanup activities conducted at many nearshore properties. Three areas were identified with exceedances of groundwater reference values that may be relevant to the evaluation of potential sediment recontamination. These areas included the following:

- Harbor Island: Elevated levels of zinc have been detected in one well (HI-12) located along the shoreline of Harbor Island. No zinc contamination has been detected in nearby EW sediments. Groundwater monitoring continues for this well as part of the compliance monitoring program for the Harbor Island Soil and Groundwater OU.
- Terminal 30: PAH parameters acenaphthene, fluorene, and phenanthrene were detected slightly above groundwater reference values in five nearshore wells (MW-84B, MW-85B, MW-86B, MW-86C, and MW-87B). Nearby sediments exceeded acenaphthene, fluorene, and phenanthrene SQS sediment criteria adjacent to the T-30 property, but did not exceed the CSL criteria. The Port and Ecology are evaluating these data as part of the ongoing investigation and cleanup of this site.
- Pier 35 (USCG): Elevated levels of arsenic were detected in one well (SB-SC-05) located at the USCG property. The detected arsenic value exceeded the groundwater reference value based on protection of sediment quality, and arsenic concentrations exceeded CSL sediment criteria adjacent to the USCG property. Results indicate that the measured arsenic concentration at one location is a potential concern for sediment recontamination based on the natural background value (7 mg/kg dw), but would not be expected to cause an exceedance of the benthic sediment cleanup objective (SCO) value (57 mg/kg dw). Comparing to natural background-based reference values is conservative for analysis of point-by-point groundwater quality data, because this does not consider the effects of spatial averaging relevant to the risk exposure scenarios on which the RBTCs are based. No groundwater monitoring is ongoing at the USCG facility. Groundwater source control at the USCG property may be addressed programmatically by EPA and/or Ecology, or may be evaluated and addressed as part of remedial design.
- T-25: Elevated levels of acenaphthene were detected in one well (AQ-MW-1) located on the T-25 property. The detected acenaphthene values exceeded the reference values based on protection of sediment quality. Several PAHs, including acenaphthene, exceeded the CSL sediment criteria adjacent to the T-25 property, which is within an existing field of creosote-treated timber pilings. Elevated

concentrations of acenapthene in nearshore groundwater are attributed to tidal exchange of PAH contamination in the intertidal bank sediments associated with creosote-treated timber structures present adjacent to the nearshore monitoring wells (Anchor QEA 2012b). Additionally, results of past studies in the upland property area do not identify sources of acenaphthene. No groundwater monitoring is ongoing at T-25. Groundwater source control at T-25 may be addressed programmatically by Ecology or may be evaluated and addressed as part of remedial design.

Groundwater discharges are not accounted for in the sediment transport evaluation (Section 5). As discussed in the SRI (Section 9.4.4, Table 9-20, Figures 9-20 through 9-24, and Appendix J), groundwater has been remediated at several sites around the EW under state and federal cleanup programs to address potential ongoing fluxes of groundwater contamination to the EW. Groundwater is being monitored to ensure that remedies remain protective. The resulting groundwater mass transfer to sediment through equilibrium partitioning is likely to be localized and insignificant compared to other mass inputs to the EW (i.e., sedimentation). Groundwater monitoring data will be used to confirm the absence of a source of contamination to EW sediments during the source control sufficiency evaluation in remedial design and during 5-year reviews.

Bank Erosion

Unprotected bank soils can be susceptible to erosion through surface water runoff, wind waves, and the action of vessel wakes and propwash. If shoreline soils are contaminated, erosion can represent a complete pathway of pollutants to the EW. The presence of shoreline armoring and vegetation affect the potential for bank erosion. Bank slope and soil properties are also factors in the susceptibility of bank areas to erosion; steeper banks are more susceptible to erosion for any given grain size. Currently, nearly all of the EW shoreline is armored with constructed steel, wood, and concrete bulkheads; sheetpile walls; and riprap revetments, which reduce the potential for bank erosion. A small percentage (less than 3%) of the banks contain non-engineered rubble armored slope or non-engineered mud or gravel. No banks were characterized as non-engineered steep banks resulting in higher potential for bank erosion.

The banks that were identified for additional considerations underlie the Spokane Street Bridge (Bank 8B) and adjacent to the USCG Facility (Bank 1 and 2B) as shown in Maps 9-25a through 9-25c of the SRI (Windward and Anchor QEA 2014). These banks are considered as part of alternative development in Section 8. Further evaluations may also be required as part of the post-ROD remedial design.

Atmospheric Deposition

Chemicals are emitted to the air from both point and non-point sources. Point sources include emissions (e.g., "stack emissions") from various stationary (i.e., "fixed" or immobile) industrial facilities (EPA 2001). Non-point sources include emissions from mobile sources such as motor vehicles, marine vessels, and trains, as well as emissions from common materials (e.g., off-gassing from plastics) and road dust resulting from urban traffic. Chemicals emitted to the air may be transported over long distances, generally in the direction of the area's prevailing winds. They can be deposited from the atmosphere to land and water surfaces through wet deposition (precipitation) or dry deposition (as particles) and are a complete pathway to the EW.

Air pollutants can enter waterbodies through either direct or indirect deposition. Direct deposition occurs when particulates with adsorbed chemicals are deposited onto the surface of a waterbody and then settle to the bottom, becoming part of the sediment. Indirect deposition occurs when chemicals are first deposited on land or other waterbodies in the watershed (e.g., streams and lakes) and then transported to the waterbody via surface water or stormwater runoff. Air pollutants deposited in the drainage basin can be transported either in dissolved form or adsorbed to solids in the runoff and are ultimately transported to bottom sediments and the water column. Many air pollutants deposited through direct or indirect atmospheric deposition in aquatic systems, such as the EW, have the potential to contaminate sediment because they are hydrophobic and tend to adhere to sediment particles (PSCAA 2003).

Direct air deposition mass transfer has not been evaluated as part of the pathway characterization. After the submittal of the SRI, King County completed the *Lower Duwamish Waterway Source Control: Bulk Atmospheric Deposition Study Draft Data Report* (King County 2013). The updated atmospheric data and select historical studies (King County 2008) are evaluated in Section 9.

Indirect air deposition was included as part of the direct discharge pathway characterization data (SDs and CSOs) in the SRI (Windward and Anchor QEA 2014). Mass transfer associated with indirect atmospheric deposition (and deposited to the EW via direct discharge) is incorporated into Section 5 evaluations.

Spills and Leaks

Spills and leaks, containing chemical contamination, to soil, other ground surfaces (such as roadways), or surface water are a potentially complete pathway to the EW. Leaks can occur from pipes and storage tanks, industrial or commercial equipment, and process operations. Spills can occur accidentally during vehicle fueling and maintenance, or purposefully in the case of illegal dumping. Spills can be a complete pathway when they discharge directly to the EW via nearshore or overwater operations, or a source when indirectly discharged into SDs or combined sewer systems with CSOs to the EW or by movement through soil to groundwater or erosion of impacted soil. Spills occurring in upland areas are incorporated into the direct discharge pathways (SD and CSO), which is further evaluated in Section 5. Spills directly to the EW are considered potential recontamination sources inherent in any commercial/industrial waterway. Any future spills in the EW will be managed under existing spill prevention and response programs and evaluated for sediment recontamination potential on a case-by-case basis.

Abrasion and Leaching of Treated-wood Structures

Historically, pilings and other wooden structures treated with creosote or other preservatives were commonly used as part of navigation or berthing improvements (e.g., wooden pier and wharf structures, fender systems, and dolphins) and marine structures (e.g., wooden bulkheads). These treated-wood structures are a potential source of contaminants, which can be released to sediments by abrasion or leaching pathways. Studies at other sites in the region indicate that the impact of treated-wood structures on sediments tends to be localized and results in steep concentration gradients of contaminants in sediments within a few feet from structures (e.g., Goyette and Brooks 1998; Poston 2001; Weston and Pascoe 2006). Although abrasion and leaching of pilings are not accounted for in the sediment transport evaluation (Section 5), the FS baseline dataset shows patterns that are consistent with these findings.

Transport of Surface Water and Sediment

Surface water inputs and suspended sediment are transported to the EW from upstream (the Green/Duwamish River and LDW) and from Elliott Bay. The input amounts and types vary greatly during the year; the Green/Duwamish system is variable, and it can be influenced by ongoing contaminant inputs from a large area of mixed industrial, commercial, residential, and agricultural lands. The LDW upriver of the EW is also a CERCLA site with contaminated sediments. Contaminants (both dissolved and particulate) released from outside of the EW drainage basins have the potential to enter the EW through transport of sediments and water from upriver or Elliott Bay. As presented in the SRI (Windward and Anchor QEA 2014) sediment contaminant levels were lowest in the northern portion of the EW, adjacent to Elliott Bay. Sediments in this area are below SQS chemical and/or biological testing criteria, suggesting that transport of Elliott Bay sediments to the EW does not pose a significant potential for sediment recontamination.

As described in the SRI (Windward and Anchor QEA 2014), 99% of the incoming solids to the EW are from the Green River and approximately 0.7% are from the LDW (bed sediments and lateral loads). Based on the evaluations in the SRI, solids from Elliott Bay are negligible in relation to other mass inputs. Sediment transport into the EW is a complete pathway and is evaluated in Section 5.

2.12 Source Control

Understanding ongoing sources of contamination and their potential impact to EW sediments is an important consideration for the cleanup of the EW. As such, an extensive source control evaluation was conducted as part of the SRI/FS.

The goals of the source control evaluation work for the SRI/FS were defined in the Work Plan (Anchor and Windward 2007) and include the following:

- Identifying potential sources of contamination to EW sediments
- Understanding the potential for these sources to recontaminate the EW sediments
- Assessing the role of ongoing sources on the CSM for the EW
- Defining a process for identifying source control data gaps, and identifying a process for collecting relevant field data, if necessary

- Providing a basis for the evaluation of potential sources through efforts such as inspections, investigation, or other actions and identifying the processes and authorities for source control activities in the EW area
- If applicable, a prediction of potential recontamination and its effect on a cleanup decision

The Source Control Evaluation Approach Memorandum (SCEAM) describes the source control evaluation process and strategy in greater detail (Anchor and Windward 2008b). Specific source control data needs for the SRI/FS were defined in the Initial Source Control Evaluation and Data Gaps Memo (Anchor QEA and Windward 2009).

In support of the SRI development, extensive source characterization and control efforts have been conducted, supplementing data available from other ongoing programs. These existing and new data were used to characterize the pathways by which ongoing contaminant source inputs can reach and impact the EW sediments. These data also support the evaluation of potential sediment recontamination as part of this FS (see Section 5). These evaluations have been and will continue to be factored into source control decisions, which will continue during the source control sufficiency evaluation conducted during remedial design.

2.12.1 Source Control Strategy

The EW source control strategy includes continued evaluation of each of the potential ongoing source pathways listed in Section 2.11.3.2. The strategy for most source pathways is to continue to rely on existing laws, permits, and other requirements that are already in place and will continue to be in place during and after sediment cleanup. The bank erosion and abrasion and leaching of treated-wood structures source pathways are expected to be addressed as part of the remediation. Each of the existing source control-related programs will continue to generate information relevant to EW source control during the FS and through the ROD. The Port, City, County, and potentially additional parties will continue source control efforts, with reporting to EPA throughout these periods in regular EW source control update meetings.

Following issuance of the ROD, implementation planning and design for the cleanup of the EW sediments will integrate and enhance, as necessary, the evaluations of the existing source control programs. During remedial design, source control sufficiency will be evaluated to assess whether sources have been controlled to the extent necessary to commence remediation of sediments. The Port, City, County, and other parties as needed (e.g., USCG), will provide information generated as part of each source control program and make sufficiency recommendations to EPA. Information provided during this process is expected to be similar to what is currently provided as part of regular EW source control update meetings. The criteria for source control sufficiency and the phasing of source control work relative to the phasing of cleanup will be developed during remedial design. After the implementation of cleanup, the set of source control-related (discussed below) programs will continue to regulate discharges to the EW to reduce the potential for recontamination of EW sediments.

2.12.2 Source Control-related Programs

A detailed discussion of ongoing source control programs and activities was presented in Section 9.3 of the SRI (Windward and Anchor QEA 2014). The majority of the source control evaluation in the EW to date has been performed under other programs and regulations, such as NPDES (e.g., for stormwater and CSO discharges) and Model Toxics Control Act (MTCA) (e.g., for upland cleanup sites adjacent to the EW). These programs enforce stringent federal and state standards (e.g., the Clean Water Act [CWA]), and incorporate reporting and review cycles for transparency, corrective action, and adaptive management. A summary of each source control-related program and how it relates to the source control strategy is provided below:

NPDES: NPDES discharges are generally administered by Ecology, although USCG discharges are administered federally. NPDES-permitted discharges to the EW include industrial and municipal stormwater, stormwater originating from certain construction projects, and County and City CSOs. Regular monitoring and reporting is conducted as part of these programs. The continued implementation of permitted discharges requires the integration of pollutant-reducing best management practices (BMPs).

CSO Control Programs: CSO control programs by the County and City under the NPDES program (and consent decrees) will also contribute to source control in the EW. These are administered by Ecology. The County and the City also have operations and maintenance programs for the combined systems.

Compliance and Inspection Programs: The Port, County, and City conduct various inspections/site assessments, based on their applicable regulatory authority, to enhance or assess compliance of permitted dischargers. These programs will continue during and after remediation. The continued inspection and assessment of businesses and tenants operating in the EW basin to enforce or enhance compliance with source control requirements through the implementation of appropriate BMPs reduces recontamination potential.

East Waterway Source Tracing Activities: The City, County, and Port will continue to conduct source tracing and identification sampling activities to support the EW source control efforts. Source tracing sampling is designed to identify potential sources by strategically collecting samples at key locations within the storm drainage and combined sewer service areas. Additional activities may be conducted to support source control sufficiency evaluation. Source tracing and source control efforts will continue through remedy implementation to minimize potential recontamination from direct discharges from stormwater outfalls and CSOs.

Municipal Stormwater Management: Both the City's and the Port's municipal stormwater permits require development of a stormwater management plan to meet CWA and state water quality requirements. Continued implementation of municipal codes require integration of pollutant-reducing BMPs.

Site Cleanup and Associated Programs: Upland soil and groundwater adjacent to the EW has been cleaned up and monitored under Ecology-administered (MTCA) and EPA-administered (CERCLA) programs. Completion of groundwater monitoring programs will verify the protectiveness of upland remedies at state and federal cleanup sites with respect to EW sediment recontamination. Further evaluation of USCG property bank soil and groundwater quality will minimize the recontamination potential in the EW sediments in this area. Upstream sediments have been, and will be, cleaned up under CERCLA, MTCA, and

Resource Conservation and Recovery Act (RCRA) administration. The LDW cleanup and source control activities may reduce the potential for recontamination of EW sediments from ongoing upstream inputs. Timing of the LDW cleanup will be considered as part of source control sufficiency for the EW.

Spill Response: Ecology, USCG, the Port, and Seattle Public Utilities (SPU) maintain spill response programs that support source control efforts in the EW. Ongoing operation of spill prevention and response programs within the EW and its drainage basins reduces recontamination risks.

Air Quality Programs: Numerous state, federal, and local programs exist to evaluate air quality and control potential air pollution sources. Air quality and atmospheric deposition information has been collected in the vicinity of the EW by several groups, including the Puget Sound Clean Air Agency (PSCAA), Ecology, and the County. If additional information is collected in the future, it will supplement existing information.

Bank erosion and abrasion and leaching of treated-wood structures pathways will be addressed directly during cleanup. Both of these potential sources are located within the limits of the EW and will be evaluated as part of remedial design. Bank stability is an important component of dredging and capping design and will be addressed as part of geotechnical analysis. The impact of treated-wood structures within the EW (e.g., the Former Pier 24 Piling Field) will be evaluated during design and addressed as necessary by the selected alternative. Some piling removal has already been performed by individual parties in the EW, including as part of a DNR program for the removal of creosote-treated structures. Ongoing treatment, replacement, and/or removal of treated wood structures located within the EW as needed during redevelopment reduces the potential for recontamination from these sources.

2.13 Key Observations and Findings from the SRI

Key observations and findings for the SRI (Windward and Anchor QEA 2014) are summarized below:

- Over the past 100 years, the EW has been highly modified from its natural configuration of a river mouth delta to support urban and industrial development. Changes have included reductions and control of water flow, channel deepening, significant shoreline modifications, fill of shorelines, loss of intertidal habitat, and installation of riprap, pier aprons, and sheetpile walls.
- Commercial and industrial facilities are the predominant use of the shoreline.
- The EW is currently and expected to continue to be used as a commercial navigational corridor. In addition to commercial activities, the EW supports the collection of seafood by tribal members, who have tribal treaty rights to harvest seafood from EW, as well as others such as recreational fishers or individuals collecting seafood to supplement their diet.
- Despite significant habitat alterations and the presence of areas with elevated contaminant concentrations in sediment, the EW contains a diverse assemblage of aquatic species and a robust food web that includes top predators.
- The site-wide average rate of sediment deposition in the EW is approximately 1.2 cm/yr.
- Results of the LDW sediment transport modeling completed and results of the PTM for lateral sources within the EW suggest that 99% of the sediment input into the EW is from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral inputs), and less than 0.3% is from discharges within the EW itself (e.g., stormwater and CSOs).
- The Deep Main Body Reach, the Shallow Main Body Reach, and the Junction Reach may experience episodic or occasional erosion or re-suspension of surface sediments due to propwash.
- Sediment concentrations above the SMS were measured throughout the EW. The majority of the contaminant concentrations above CSL values in surface sediment were located in areas within the EW that have not recently been dredged (i.e., the Shallow Main Body Reach, the perimeter of the Deep Main Body Reach, and the slips). The locations of the highest total PCB, cPAH, arsenic, mercury, and TBT concentrations were varied.
- The distribution of contaminants in subsurface sediment was found to be similar to the distribution in surface sediment. In recently dredged areas, the subsurface sediment concentrations were generally less than the surface sediment

concentrations. However, in the Shallow Main Body Reach and areas within the Deep Main Body Reach that have not been recently dredged, the subsurface contaminant concentrations were generally greater than the surface sediment concentrations. The contaminants that exceeded the SMS in the greatest number of subsurface samples were total PCBs and mercury.

- In surface water samples in the EW, chronic aquatic life water quality criteria (WQC) were exceeded (and detected) in one sample for both cadmium and TBT. Human health WQC were exceeded (and detected) in multiple samples for arsenic[17] and total PCBs, and in no more than three samples for benzo(a)anthracene, chrysene, and BEHP.
- In groundwater samples collected from sites adjacent to the EW, chronic aquatic life WQC were exceeded for arsenic, copper, nickel, and zinc in one or more samples, and acute aquatic life WQC was exceeded for arsenic in one sample.
- Key pathways and sources of contaminants were identified, with potential sources of contaminants being the result of both historical and ongoing inputs. Source control data are available for the different pathways to evaluate recontamination potential of sediments in the FS. This evaluation will inform future source control actions in EW.

2.14 Additional Considerations for the FS

In this section, data presented in the SRI (Windward and Anchor QEA 2014) are expanded upon for the purposes of this FS. This section also discusses information not presented in the SRI that may be relevant to selecting remedial technologies and developing remedial alternatives.

2.14.1 Sediment Physical Properties

The geotechnical and physical properties of sediment (such as density, plasticity, sediment grain size, and the presence of debris) are important for developing appropriate remedial technologies. Some of the important technology considerations affected by sediment physical properties include:

[17] Note that the SRI (Windward and Anchor QEA 2014) water data represent total arsenic (i.e., the sum of the organic and inorganic arsenic species) and the criterion represents the inorganic fraction of arsenic only, so these exceedances are uncertain.

- Dredgeability or the ability to physically excavate the sediment
- Sediment handling
- Sediment dewatering
- Slope stability
- Bearing capacity for cap placement
- Consolidation settlement of sediments under cap loads

Geotechnical properties such as grain size composition, plasticity, porosity, and unit weight (as measured by bulk density) were evaluated to help understand the manner in which sediment could behave when handled during remediation.

Supplemental geotechnical testing was performed on a subset of the EW SRI subsurface sediment dataset, which included 13 subsurface core locations generally evenly distributed across the EW. Geotechnical tests included Atterberg limits (i.e., liquid limit, plastic limit, and plastic index), specific gravity, moisture content, and bulk density (dry and wet). Testing was performed on intervals that represented the major subsurface sediment units. Geotechnical properties vary with depth and with sediment type, and are summarized by EW stratigraphic groupings. In general, moisture content decreases with depth and dry bulk density increases with depth, as would be expected due to the more consolidated nature of the deeper sediments. More consolidated sediments generally have greater strength, which decreases ease of dredging but tends to increase support for sediment caps. Additional details on the geotechnical results are presented in the subsurface sediment data report (Windward 2011).

2.14.1.1 Engineered Fill, Anthropogenic Fill, and Sand Cover Layers

These layers are typically surficial within the top 1 foot below mudline. These materials are typically granular, with dry bulk density ranging from 92 to 97 pounds per cubic foot [pcf], wet bulk density ranging from 107 to 110 pcf, moisture content ranging from 14% to 15%, and a typical specific gravity of 2. 7 grams per cubic centimeter [g/cm^3]).

2.14.1.2 Recent Unit

Geotechnical tests were performed on near-surface (0 to 3 feet below mudline) recent silts. These shallow silts exhibit a range of dry bulk density from 34 to 47 pcf, a range of wet bulk density from 67 to 85 pcf, and a range of moisture content from 82% to 110%. The mean specific gravity is 2. 53 g/cm^3. Atterberg limits data indicate a mean liquid limit of 77.1% dw, a mean plastic limit of 28.2% dw, and a mean plasticity index of 48.9% dw.

2.14.1.3 Upper Alluvium Unit

Mid-depth Upper Alluvium layers (generally 2 to 5 feet below mudline) included a wide range of silts, silty sands, and silt with laminated and stratified beds of sand. Geotechnical properties span relatively larger ranges of values and are indicative of the varied nature of material in this stratigraphic layer. Dry bulk density values range from 53 to 89 pcf, wet bulk density values range from 84 to 119 pcf, and moisture content values range from 23% to 60%. Mean specific gravity is 2.65 g/cm^3. Atterberg limits tests indicate a mean liquid limit of 46.8% dw, a mean plastic limit of 23.4% dw, and a mean plasticity index of 23.4% dw.

2.14.1.4 Lower Alluvium Unit

Deeper Lower Alluvium layers (up to 10.8 feet below mudline) included a wide range of lithological composition, but generally consist of a predominantly sand matrix with laminated beds of silt. Dry bulk density ranges from 54 to 99 pcf, wet bulk density values range from 72 to 125 pcf, and moisture content values range from 24% to 42%. Mean specific gravity is 2.65 g/cm^3. Atterberg limits indicate a mean liquid limit of 37% dw, a mean plastic limit of 28.8% dw, and a mean plasticity index of 8.2% dw.

2.14.2 Debris

Submerged and emergent debris and obstructions can have a substantial impact on the selection and application of appropriate remedial technologies and overall performance of the EW remediation, particularly as it relates to dredge production rate and the generation of residuals. Encountering debris and submerged objects can damage dredge buckets and clog cutterheads, slow production, cause substantial material release of sediments out of partially opened buckets or flushed hydraulic pipelines, and, in general, impact the ability of a dredging operation to achieve cleanup standards in an effective manner. Industrial waterways such as the EW typically contain debris, deposited over decades of waterway use.

It is not feasible to fully quantify the type and vertical extent of all the debris that will be encountered during dredging until dredging is under way; however, design-level debris assessment can qualitatively identify some surficial or buried debris, including side-scan sonar, magnetometer, and diver surveys. Debris sweeps are assumed to be a part of the dredging activities for all remedial alternatives.

2.14.3 Recent Dredging Events

As described in Section 2.2, portions of the EW have been dredged multiple times since its original construction in the early 1900s. Dredging in the EW has been conducted to maintain and deepen existing berths and to deepen part of the federal navigation channel to -51 feet MLLW. Recent dredge events are summarized below and illustrated in Figure 2-22 for events occurring from 2000 to 2016:

- Stage 1 navigational dredging (December 1999 to February 2000) to -51 feet MLLW from the north end of the EW to Station 4950.
- T-30 berth dredging (2002) to -44 feet MLLW (Stations 1400 to 2900).
- Phase 1 Removal Action dredging (January 2004 to February 2005) to -51 feet MLLW (Stations 3000 to 4950). Contingency dredging occurred to -52 to -53 feet MLLW over most of the dredge footprint, which was followed by placement of sand cover material with a minimum thickness of 6 inches. Sand layer thickness measured after placement ranged from 6 inches to more than 1 foot and averaged 10 inches (Anchor and Windward 2005).
- Slip 36 dredging (August 2004 to February 2005) to -40 feet MLLW.
- T-46 maintenance dredging (2005) to -51 feet MLLW (Stations -200 to -700).
- T-30 berth deepening (conducted over two dredge seasons from January 2008 to February 2009) to -51 feet MLLW (Stations 1700 to 3500).
- T-18 dredging in Berths 2 through 5 (January 2005 to November 2006) to -51 to -52 feet MLLW (Stations 1500 to 4950).
- T-18 minor maintenance dredging (January and February 2009) to -51 feet MLLW (less than 1,000 cubic yards [cy] removed [Stations 500 to 4900]).
- T-18 maintenance dredging (February and March 2016) to -51 feet MLLW (approximately 6,200 cy of sediment removed [Stations 0 to 4950]).

Dredge records for events conducted prior to 2000 are limited and exact dimensions are not always known. Based on available data, these older dredging events included the following:

- T-25 (1970s) berth dredging to -50 feet MLLW up to the federal channel boundary.
- T-25 (1981) keyway dredging to -55 feet MLLW from Stations 4250 to 6100. This event included dredging a narrow keyway along the face of Berth 25 for construction of the T-25 riprap slope. The keyway was backfilled with riprap to approximately -50 feet MLLW. The outer edge of the excavation would likely have been less than 25 feet from the face of the pier. The keyway design width was 5 feet and the outer edge sloped from -55 feet MLLW (toe of keyway) to approximately -45 feet MLLW.
- T-30 (1980s) keyway dredging to -55 feet MLLW from Stations 1600 to 3600 before being backfilled with riprap. This keyway dredging was similar to the T-25 keyway dredging described above.

2.14.4 Seismic Conditions

This section summarizes seismic conditions that were presented in LDW FS (AECOM 2012), which are also directly applicable to the EW. The Puget Sound region is vulnerable to earthquakes originating primarily from three sources:

1. The subducting Juan de Fuca plate (intraplate)
2. Between the colliding Juan de Fuca and North American plates (subduction zone)
3. Faults within the overriding North American plate (shallow crustal)

Earthquakes have the potential, depending on epicenter, magnitude, and type of ground motion, to change the vertical and lateral distribution of contaminated sediments in the EW and soil in the EW drainage basin and surrounding upland areas. This potential is considered during the development and evaluation of remedial alternatives in this FS and will be refined during the remedial design phase.

The following are examples of regional earthquakes by source, estimated probability of occurrence in any given 50-year interval, type and date of events that have historically occurred, and their magnitude (Moment Magnitude Scale [M][18]) (EERI and WMDEMD 2005):

- Intraplate (84% probability):
  - Nisqually 2001, M6.8
  - Seattle-Tacoma 1965, M6.5
  - Olympia 1949, M6.8
- Subduction Zone (10% to 14% probability):
  - January 1700, M9 (estimated)
  - Shallow Crustal (5% probability)
  - Seattle Fault (approximately 1,100 years ago), M6.5 or greater

Of particular concern to regional planners is a large earthquake on the Seattle Fault, similar to the one that occurred approximately 1,100 years ago and caused a fault displacement of the bottom of Puget Sound by several feet. The geologic record shows that this earthquake caused a 22-foot uplift of the marine terrace on southern Bainbridge Island, numerous landslides in Lake Washington, and landslides in the Olympic Mountains (Bucknam et al. 1992). Upland sand deposits at West Point, north of Elliott Bay, and at Cultus Bay on the southern end of Whidbey Island (Atwater and Moore 1992) suggest that that earthquake produced a tsunami that deposited up to 10 feet of material in some upland areas.

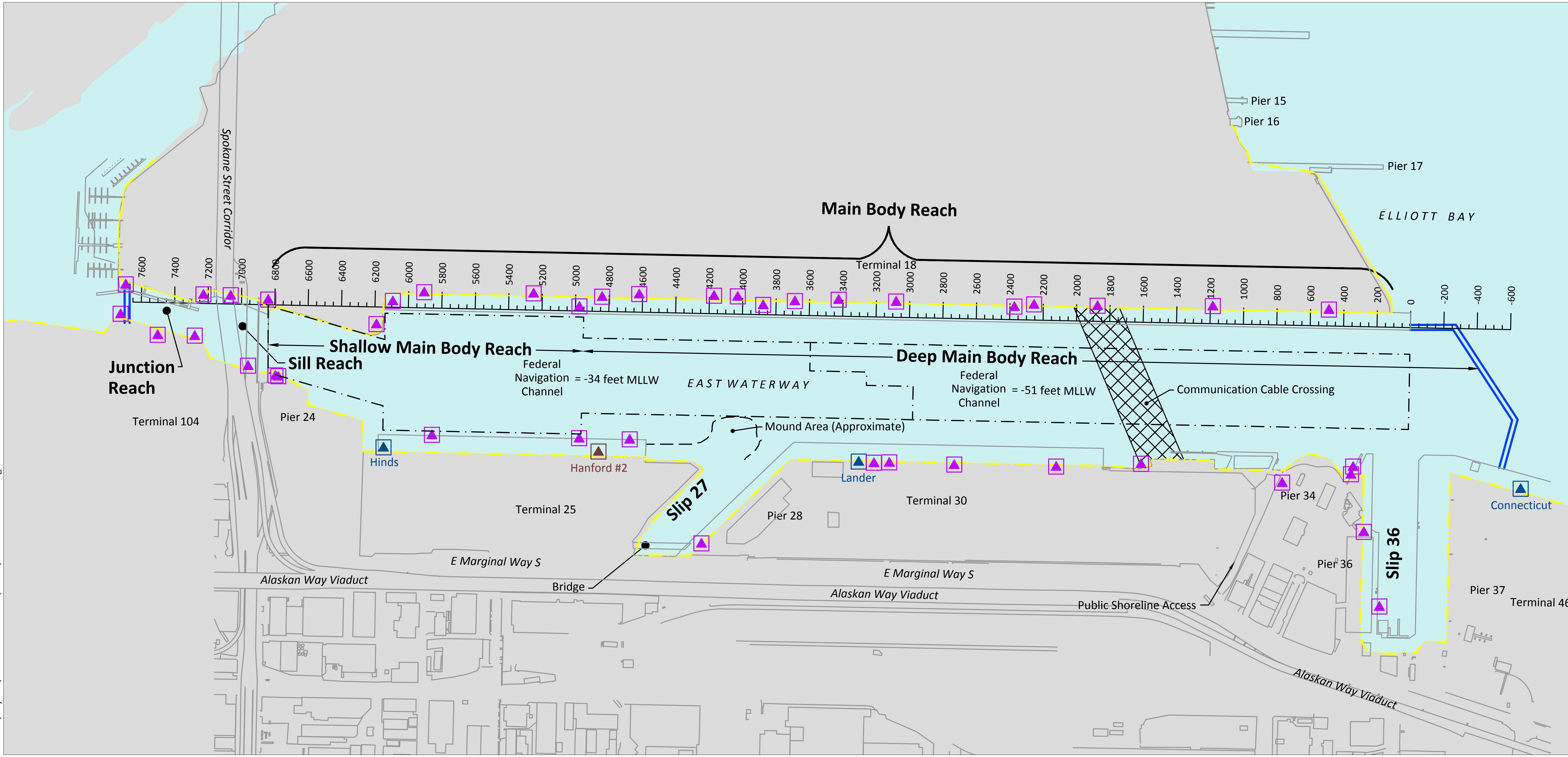
The Seattle Fault is believed to be capable of generating another major earthquake of M7 or greater (Pratt et al. 1997; Johnson et al. 1996, Brocher et al. 2000). A hypothetical Seattle Fault earthquake scenario was developed for guiding regional preparation and responses to such a foreseeable event (EERI and WMDEMD 2005). The earthquake in this scenario was of

[18] The Moment Magnitude Scale (M) is used by the U.S. Geological Survey to measure the size of large earthquakes in terms of the energy released. This logarithmic scale was developed in the 1970s to succeed the Richter magnitude scale. It provides a continuum of magnitude values; moderate events have magnitudes of greater than 5.0 and major earthquakes have magnitudes of greater than 7.0. Great earthquakes have magnitudes of 8.0 or higher. Moment Magnitude considers the area of rupture of a fault, the average amount of relative displacement of adjacent points along the fault, and the force required to overcome the frictional resistance of the materials in the fault surface and cause shearing.

magnitude M6.7, which has an estimated 5% probability of occurrence in any given 50-year period (once in approximately 1,000 years). This scenario is based on a shallow epicenter with a surface fault rupture (as opposed to the deeper epicenters with other recent events such as Nisqually [2001], Seattle- Tacoma [1965], and Olympia [1949]). The Seattle Fault scenario would have major consequences for liquefaction-induced ground movements that could damage in-water and upland infrastructure in the EW and Green/Duwamish River valleys. Under the scenario, ground deformation could be up to 3 feet, which would impact seawalls and release upland soils into the EW. An earthquake of this magnitude would also likely cause widespread disruption of essential services.

Tsunamis could also affect the vertical and horizontal distribution of sediment contamination remaining in the EW following cleanup and could contribute additional contaminants derived from other sources. Titov et al. (2003) modeled a M7.3 earthquake at the Seattle Fault and the resulting tsunami bore was modeled southward to approximately river mile (RM) 1.5 on the LDW. The modeled tsunami would inundate Harbor Island, the South of Downtown District, and uplands along the EW and LDW. The model also predicts some locally high velocities over the bench areas as the bore moves through the EW and lower reach of the LDW. EW soils are classified as being susceptible to liquefaction (Palmer et al. 2004), which would tend to magnify earthquake-induced motion.

Section 8 includes considerations of seismicity with respect to other feasibility studies and remedial designs for other projects in the vicinity of the EW and the adjacent Elliott Bay.



NOTE:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.

LEGEND:

- East Waterway Study Boundary
- MHHW Line
- Federal Navigation Channel
- CSO
- Storm Drain
- CSO/Storm Drain

0 600
Scale in Feet

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Figure 2-1
Major East Waterway Features
Feasibility Study
East Waterway Study Area

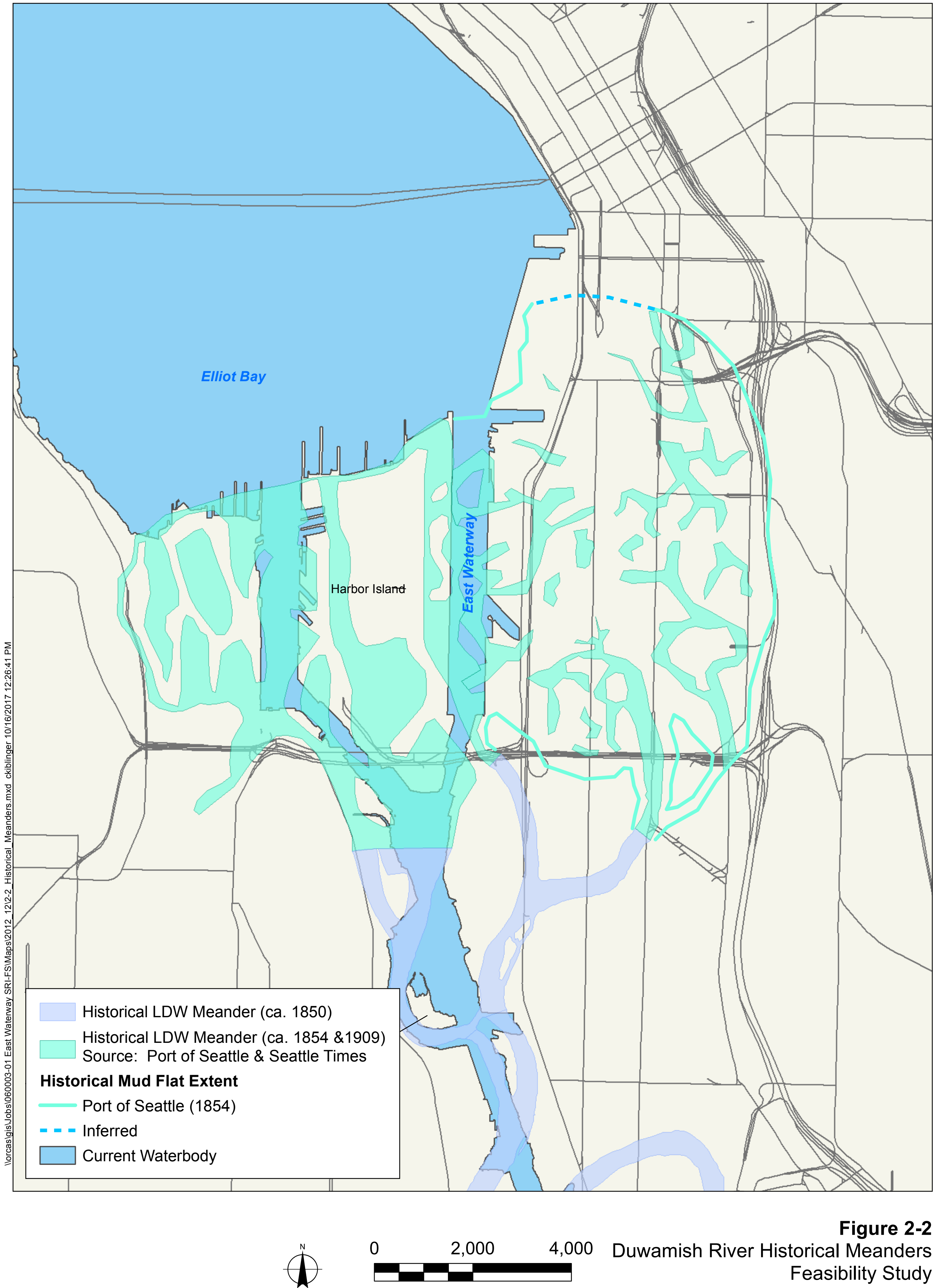


Figure 2-2
Duwamish River Historical Meanders
Feasibility Study
East Waterway Study Area

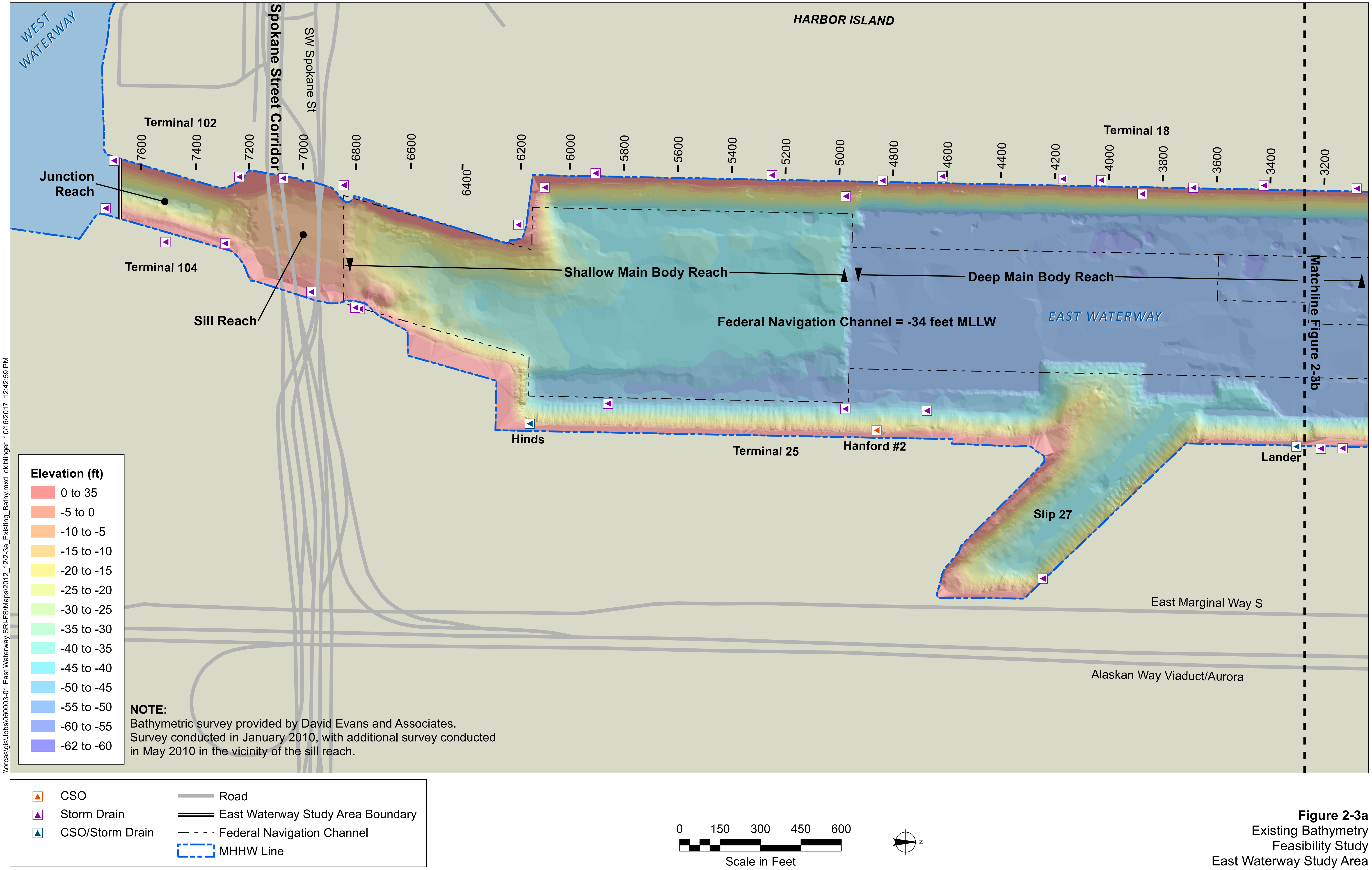


Figure 2-3a
Existing Bathymetry
Feasibility Study
East Waterway Study Area

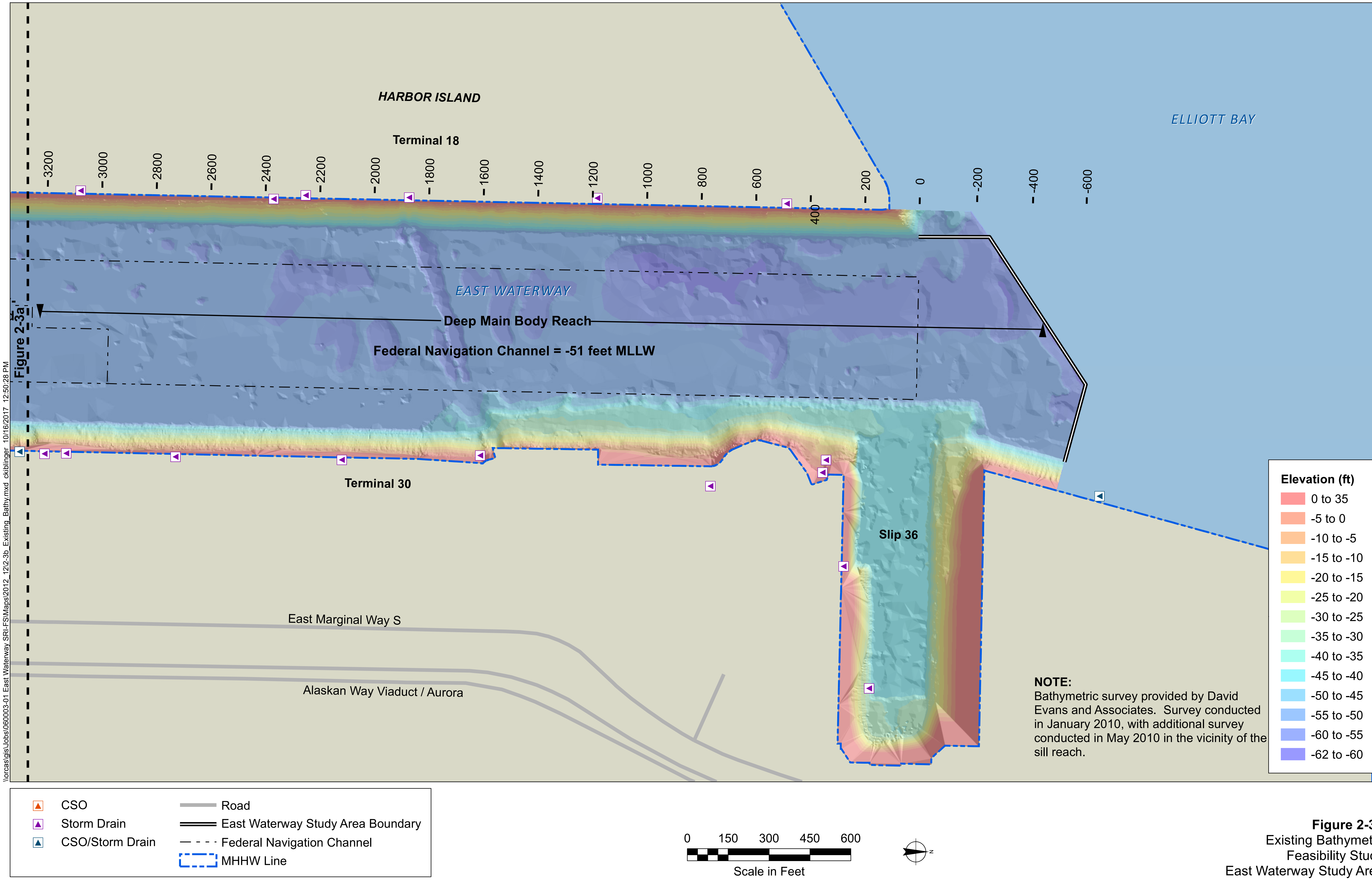
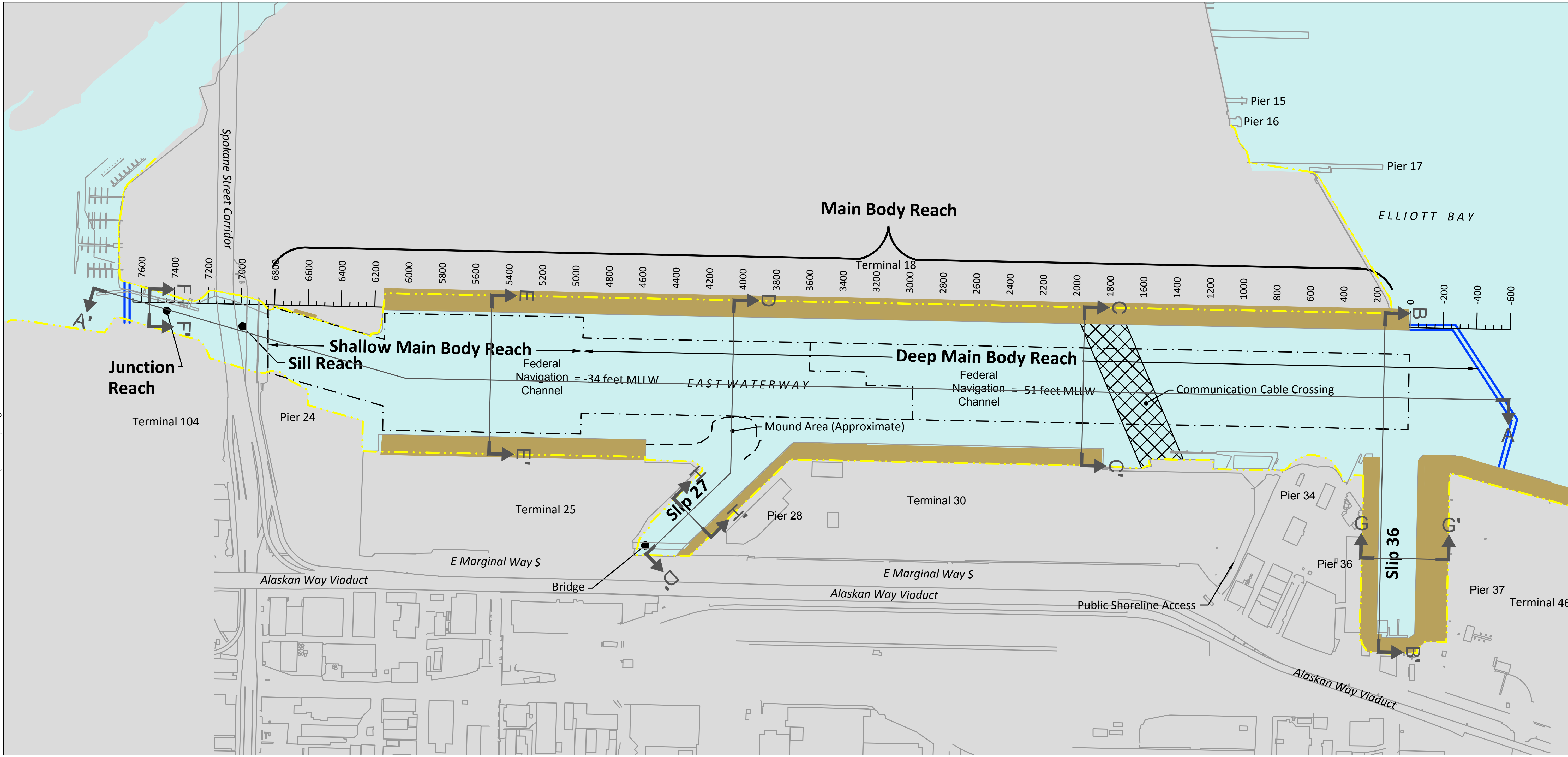


Figure 2-3b
Existing Bathymetry
Feasibility Study
East Waterway Study Area



K:\Jobs\060003-PORT OF SEATTLE\060003-01\06\060003-01-RP-067 (Sections).dwg 2-4a

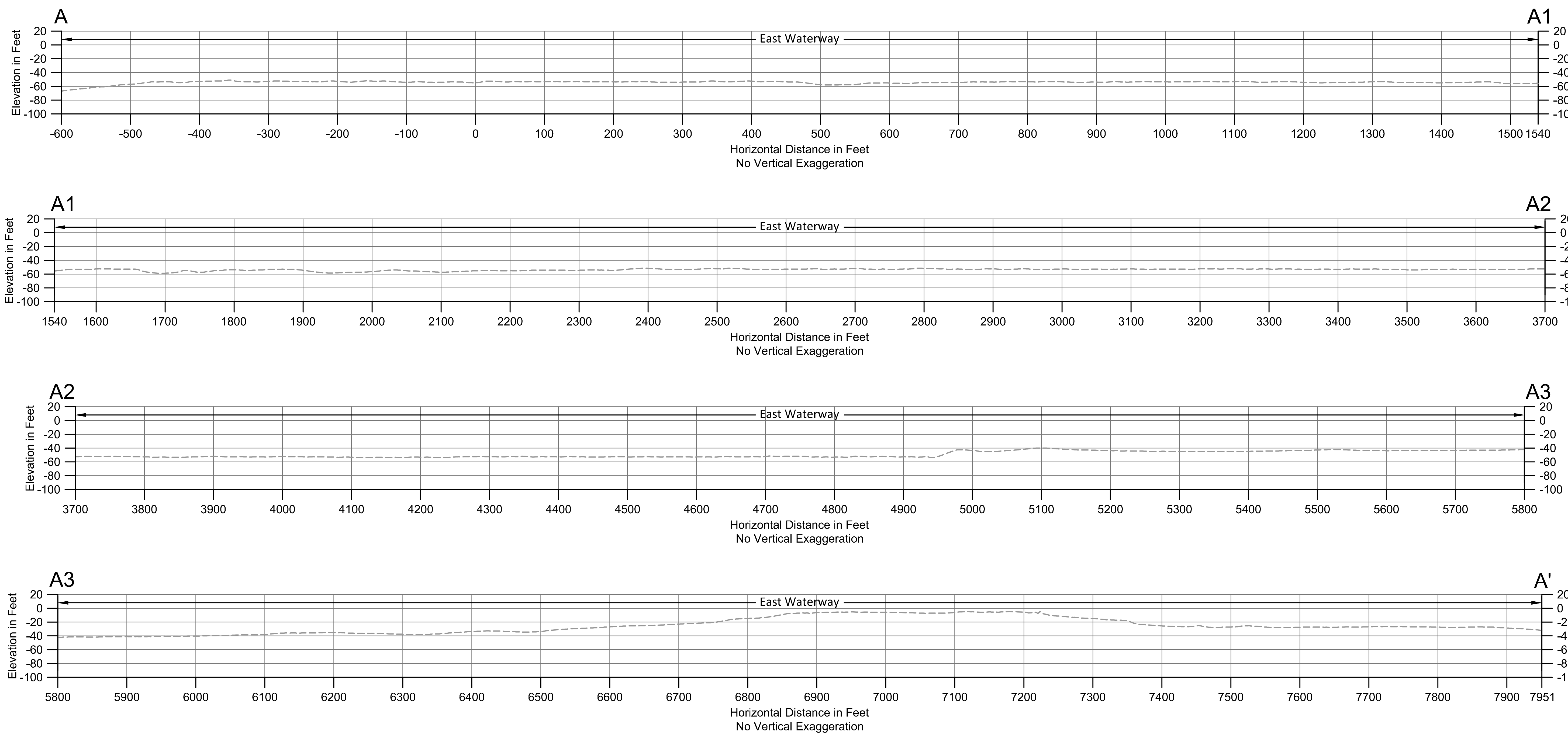
Jan 08, 2016 12:29pm chewett

NOTES:
1. Cross-sections are shown on Figures 2-4b-d.

LEGEND:
- East Waterway Study Boundary
- MHHW Line
- Federal Navigation Channel
- Overwater Pier Above Riprap
- A A' Cross Section Location

0 600 Scale in Feet

Figure 2-4a
Cross-section Plan View
Feasibility Study
East Waterway Study Area



SOURCE: Existing bathymetry survey provided bv David Evans and Associates.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

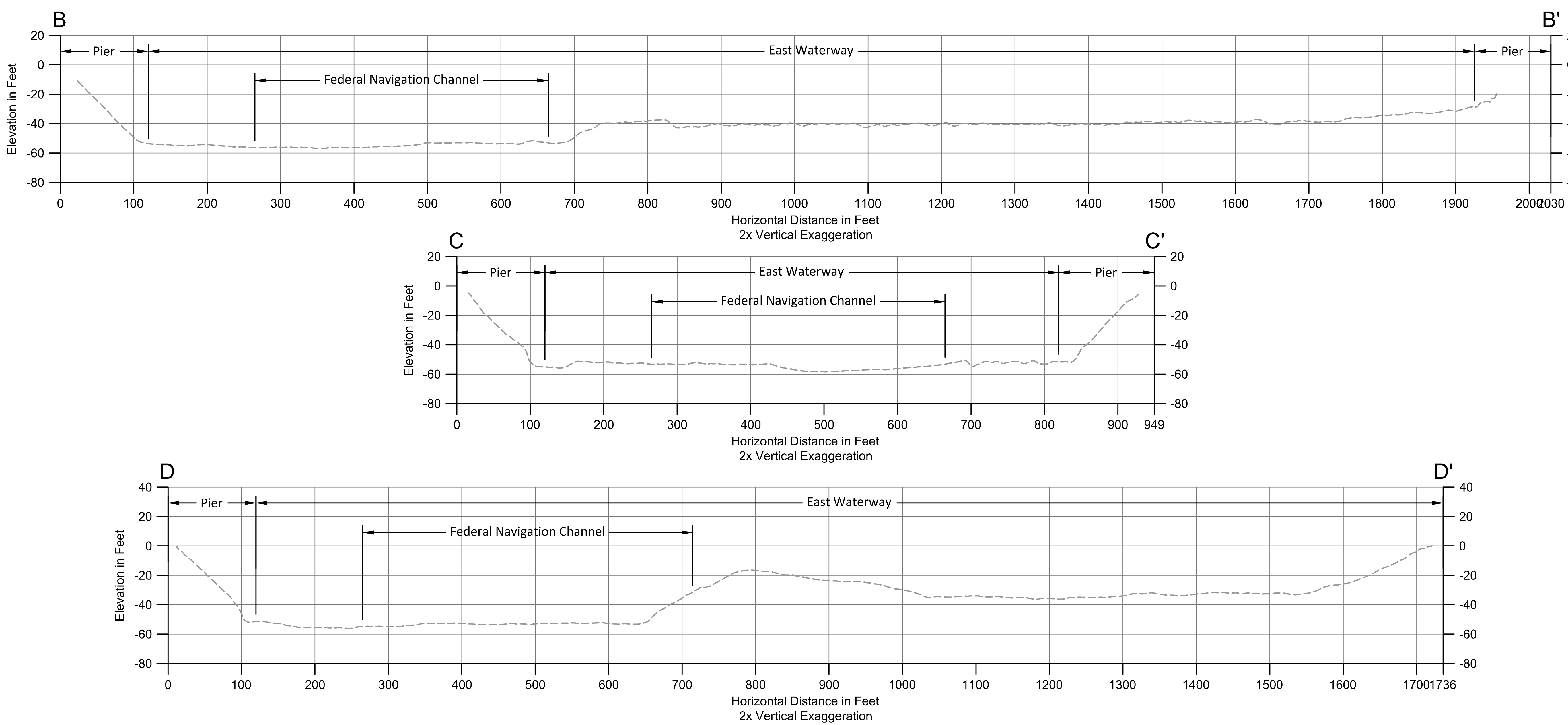
NOTES:
1. Cross-section locations are shown on Figure 2-4a.

LEGEND:

Existing Mudline

ANCHOR QEA

Figure 2-4b
Cross-sections
Feasibility Study
East Waterway Study Area



SOURCE: Existing bathymetry survey provided bv David Evans and Associates.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

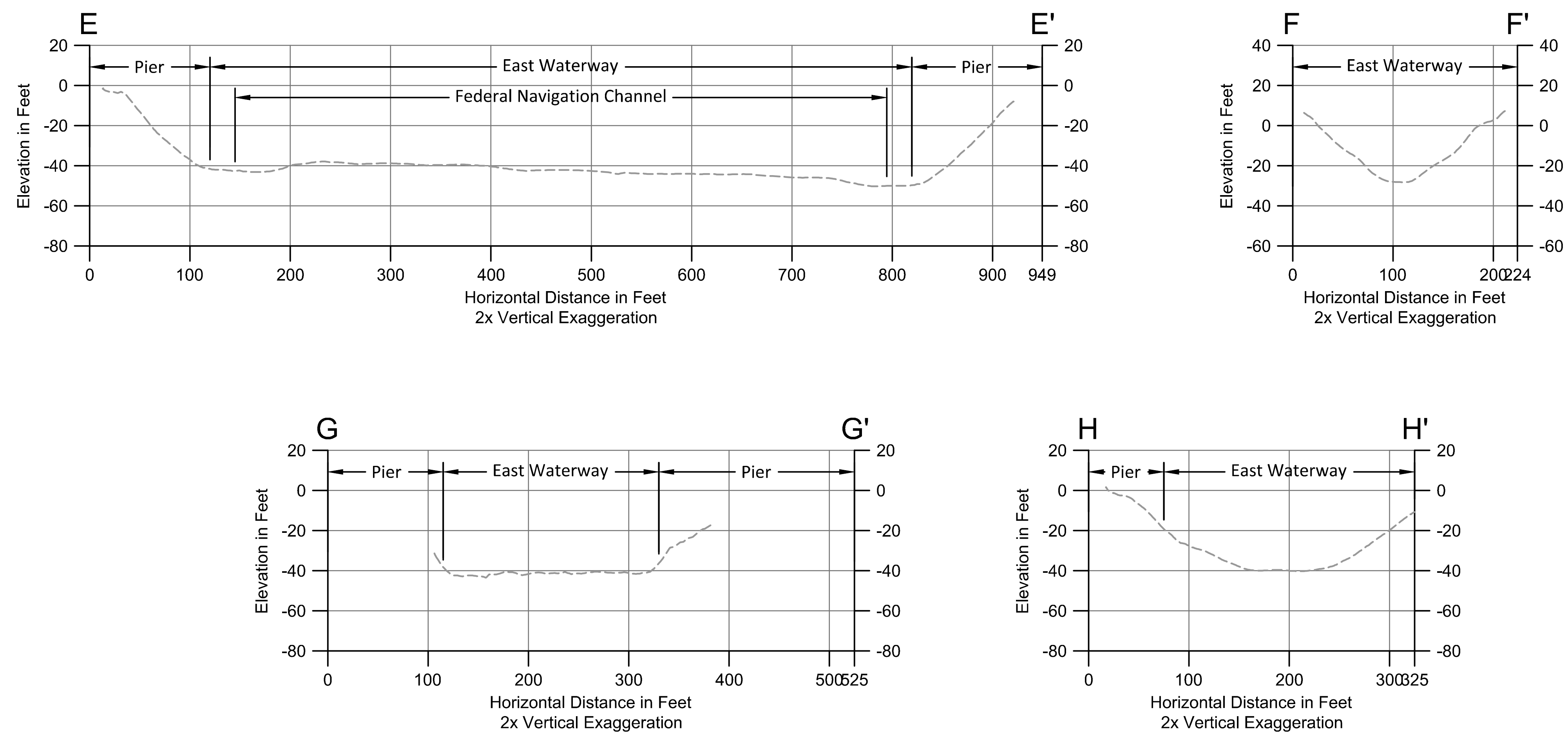
NOTES:
1. Cross-section locations are shown on Figure 2-4a.

LEGEND:

- - - - - - Existing Mudline

ANCHOR QEA

Figure 2-4c
Cross-sections
Feasibility Study
East Waterway Study Area



SOURCE: Existing bathymetry survey provided bv David Evans and Associates.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

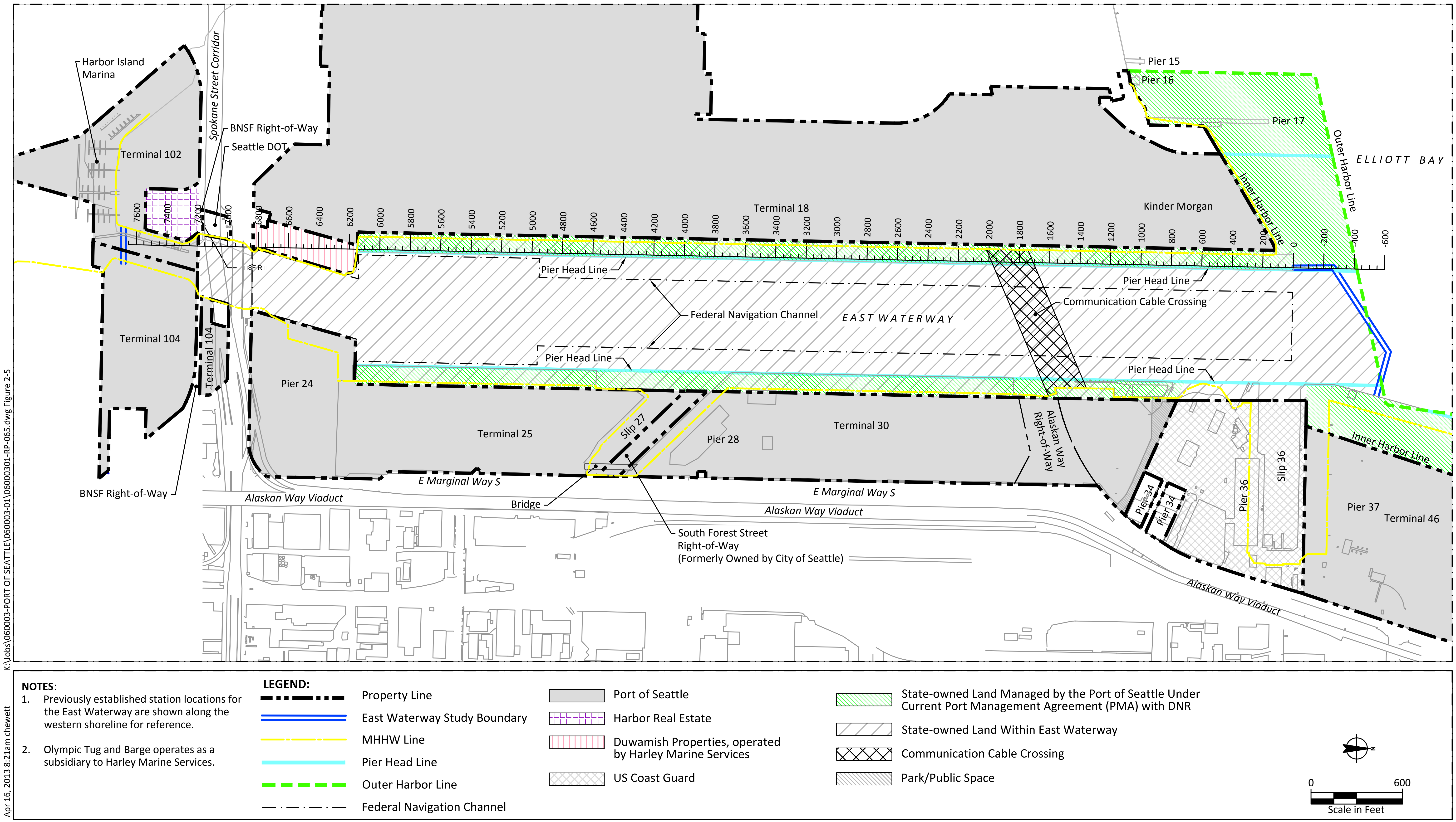
NOTES:
1. Cross-section locations are shown on Figure 2-4a.

LEGEND:

------- Existing Mudline

ANCHOR QEA

Figure 2-4d
Cross-sections
Feasibility Study
East Waterway Study Area



K:\Jobs\060003-PORT OF SEATTLE\060003-01\06000301-RP-065.dwg Figure 2-5

Apr 16, 2013 8:21am chewett

Figure 2-5
Upland and Aquatic Ownership
Feasibility Study
East Waterway Study Area

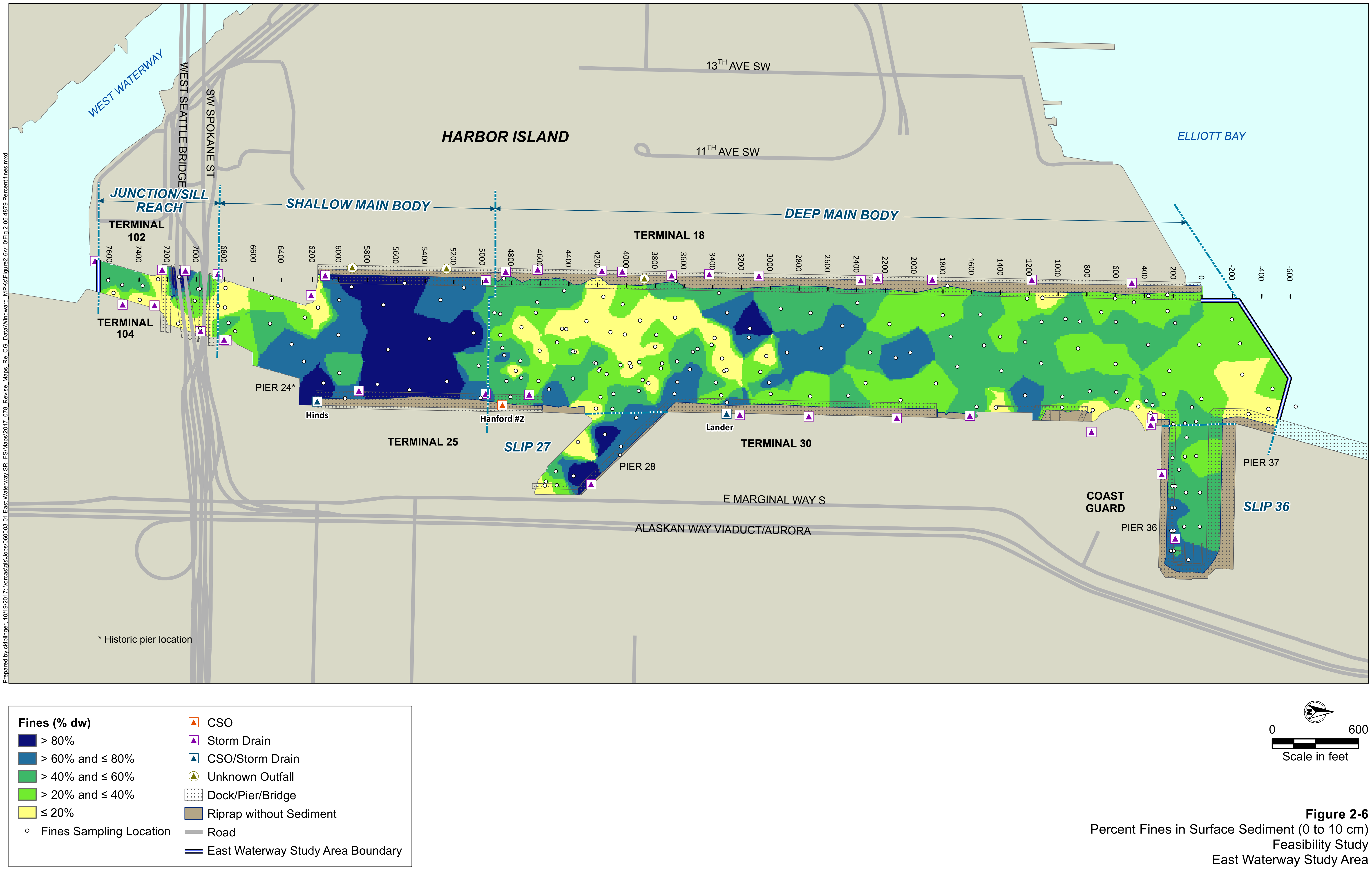
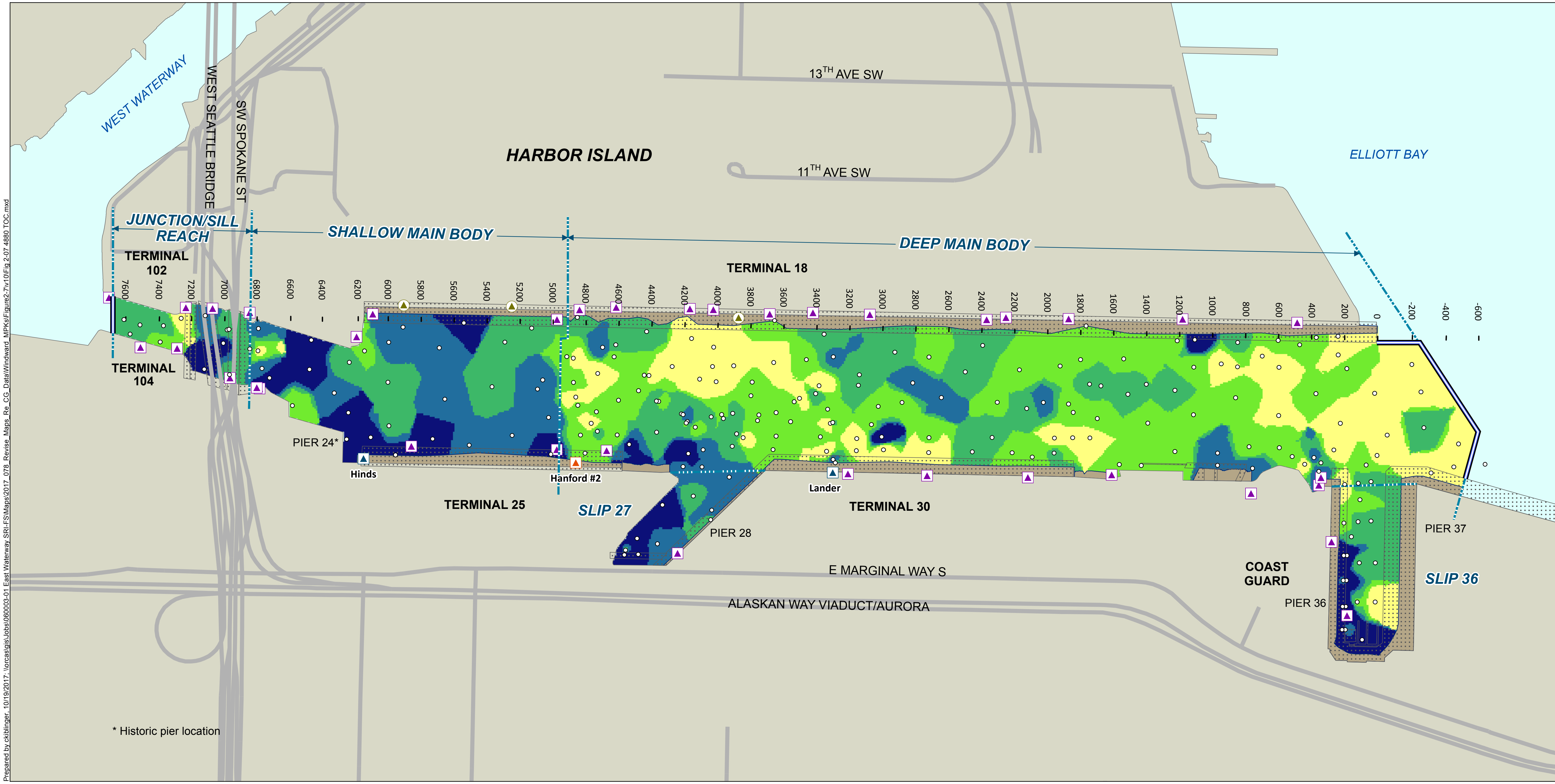


Figure 2-6
Percent Fines in Surface Sediment (0 to 10 cm)
Feasibility Study
East Waterway Study Area

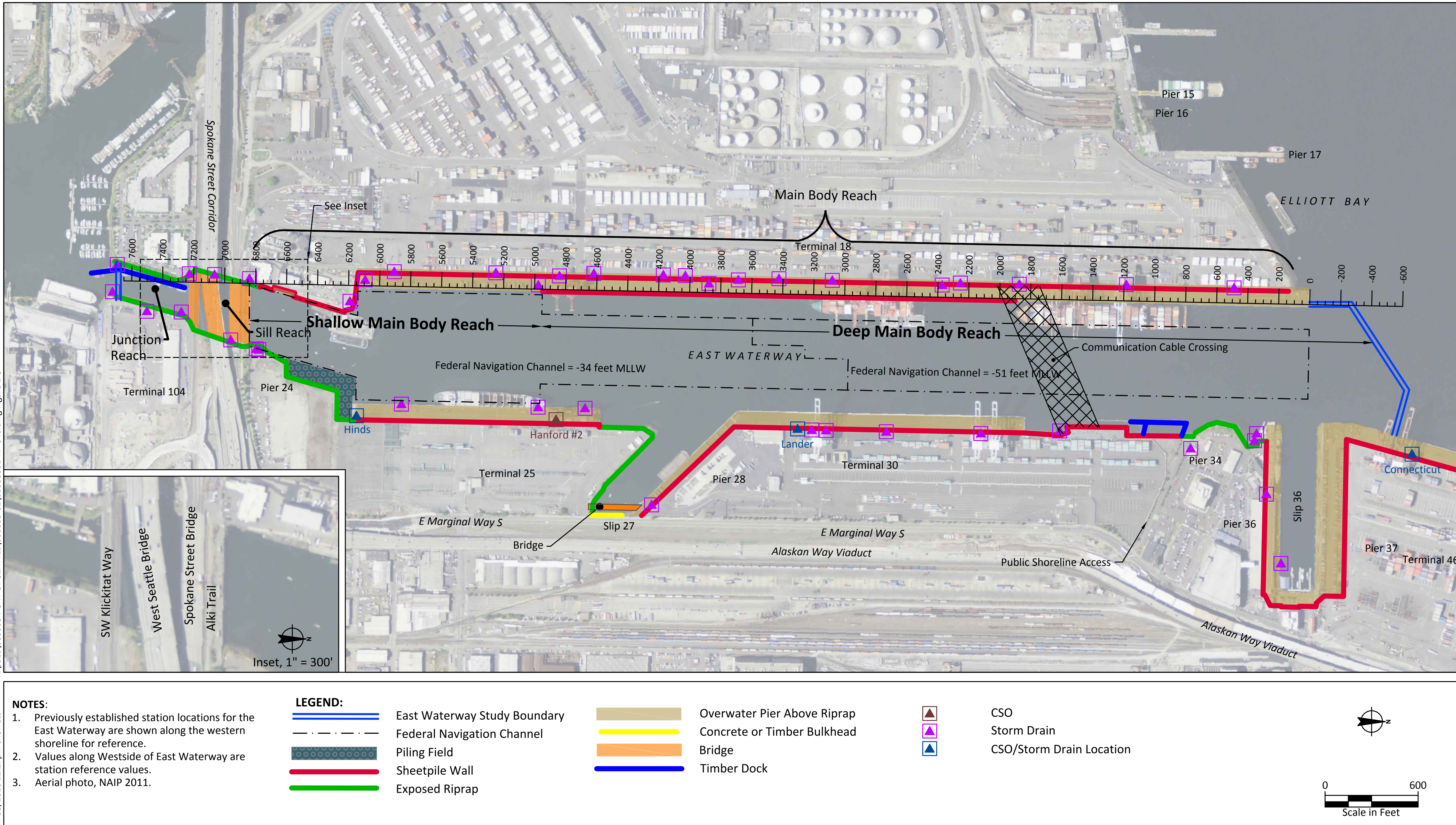


Total organic carbon (% dw)
- > 2.5%
- > 2% and ≤ 2.5%
- > 1.5% and ≤ 2%
- > 1% and ≤ 1.5%
- ≤ 1%
- Total Organic Carbon Sampling Location

- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary

0 600
Scale in feet

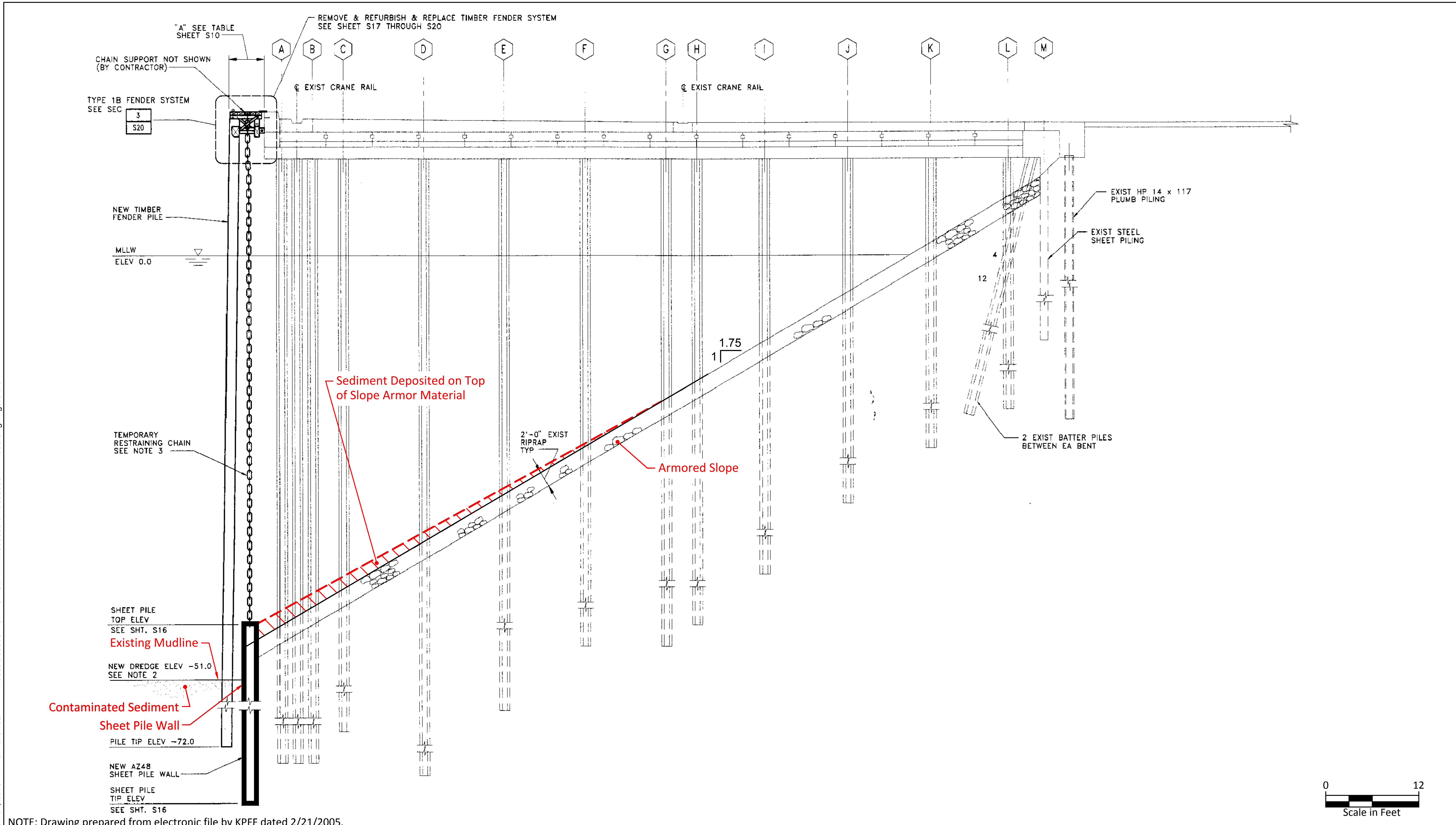
Figure 2-7
Total Organic Carbon in Surface Sediment (0 to 10 cm)
Feasibility Study
East Waterway Study Area



K:\Jobs\060003-PORT OF SEATTLE\060003-01\06000301-RP-040.dwg Figure 2-8

Jan 08, 2016 12:27pm chewett

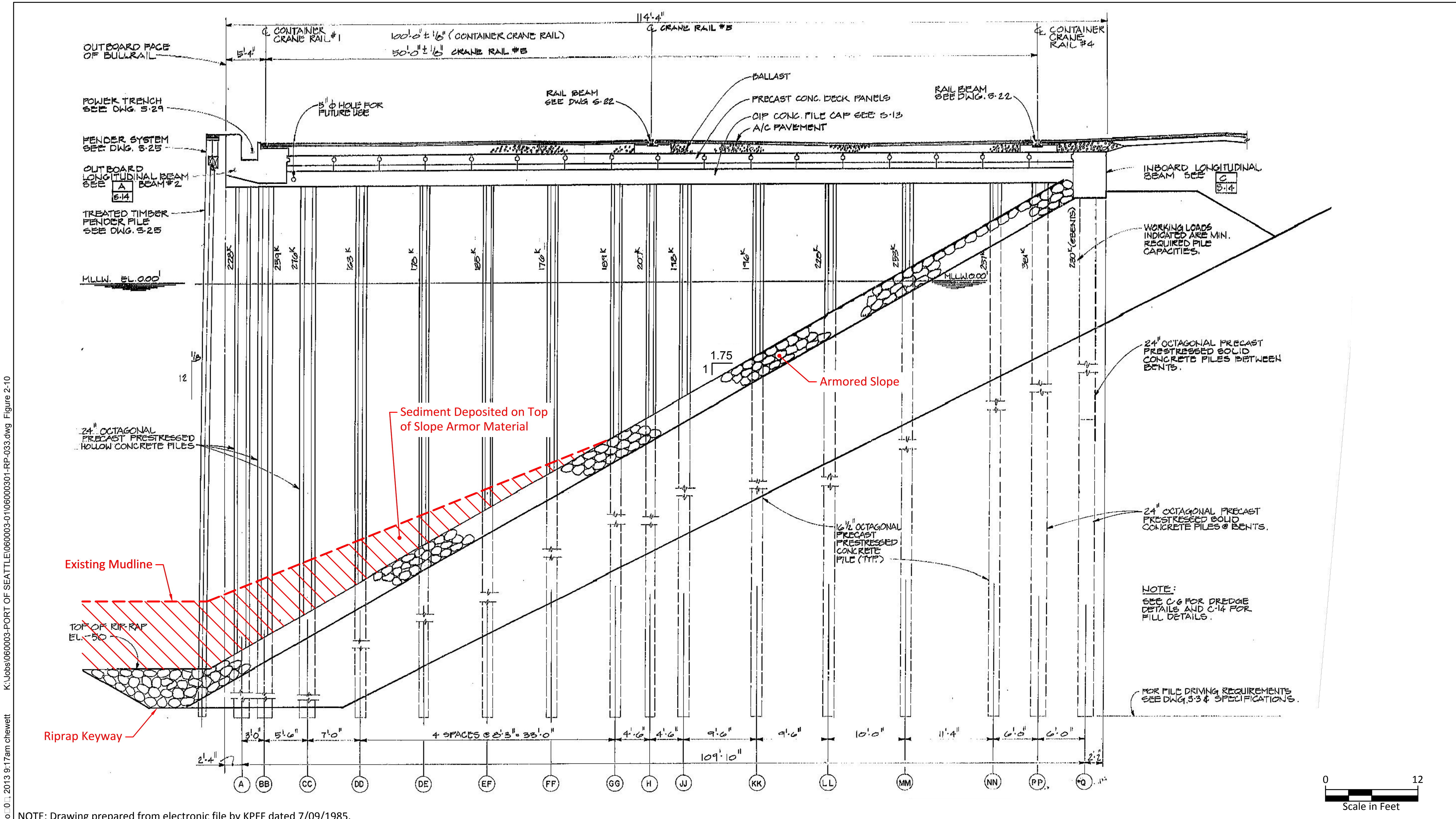
Figure 2-8
Shoreline Conditions and Structures
Feasibility Study
East Waterway Study Area



NOTE: Drawing prepared from electronic file by KPFF dated 2/21/2005.

Jan 07, 2016 11:44am chewett K:\Jobs\060003-PORT OF SEATTLE\060003-01\06000301-RP-033.dwg Figure 2-9

Figure 2-9
Typical Cross Section of Terminal 18 Sheetpile Toe Wall
Feasibility Study
East Waterway Study Area



NOTE: Drawing prepared from electronic file by KPFF dated 7/09/1985.

Figure 2-10
Typical Cross Section of Terminal 25 and 30
Feasibility Study
East Waterway Study Area

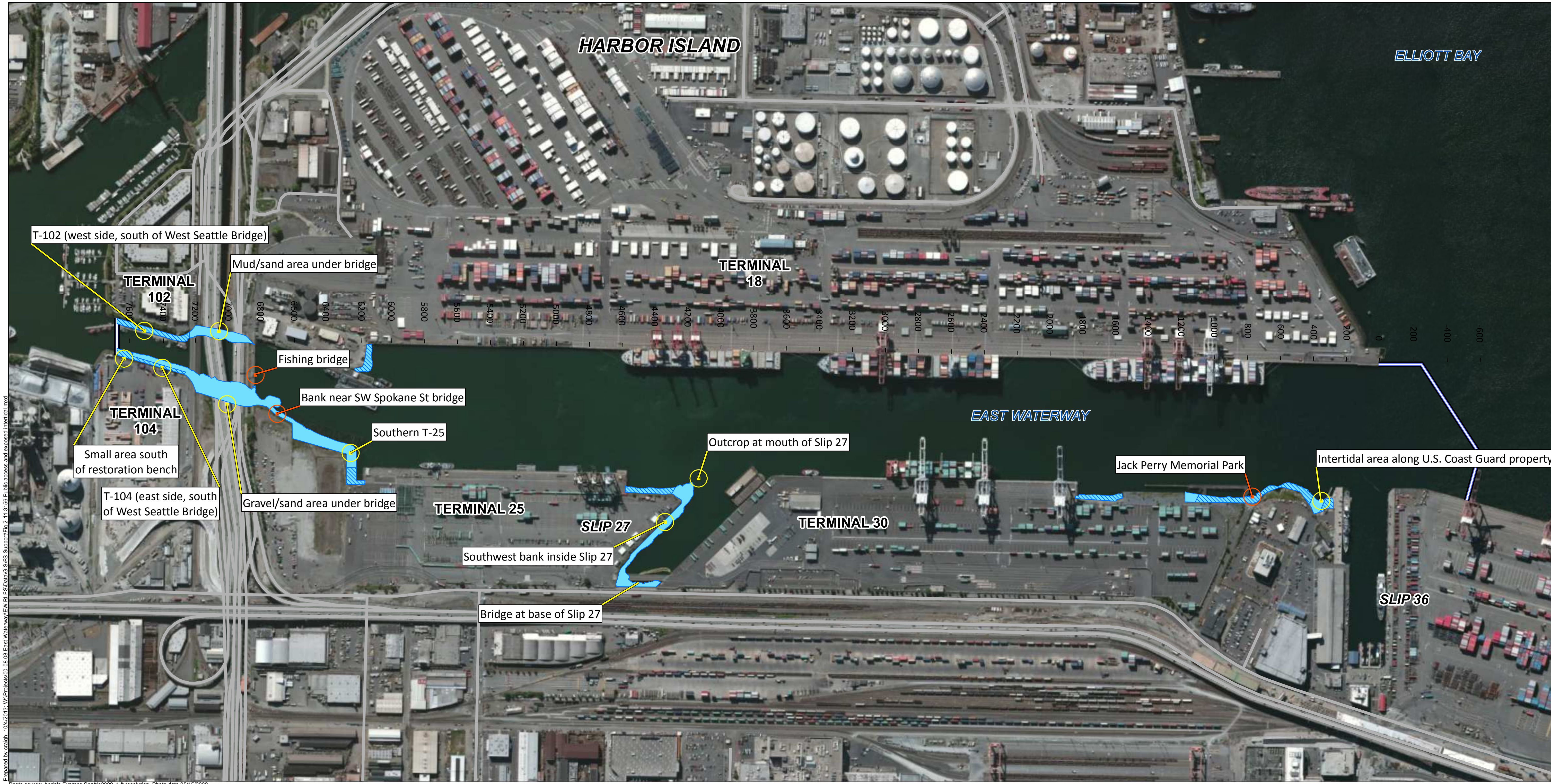


Photo source: Aerials Express Seattle2009, 1 ft resolution. Photo date 05/15/2009.

- Public Access Location
- Exposed Intertidal Location
- Exposed Intertidal Area
- Fully Armored Exposed Intertidal Area
- East Waterway Study Area

0 600
Scale in feet

Figure 2-11
Public Access Locations and Exposed Intertidal Areas Within the East Waterway
Feasibility Study
East Waterway Study Area

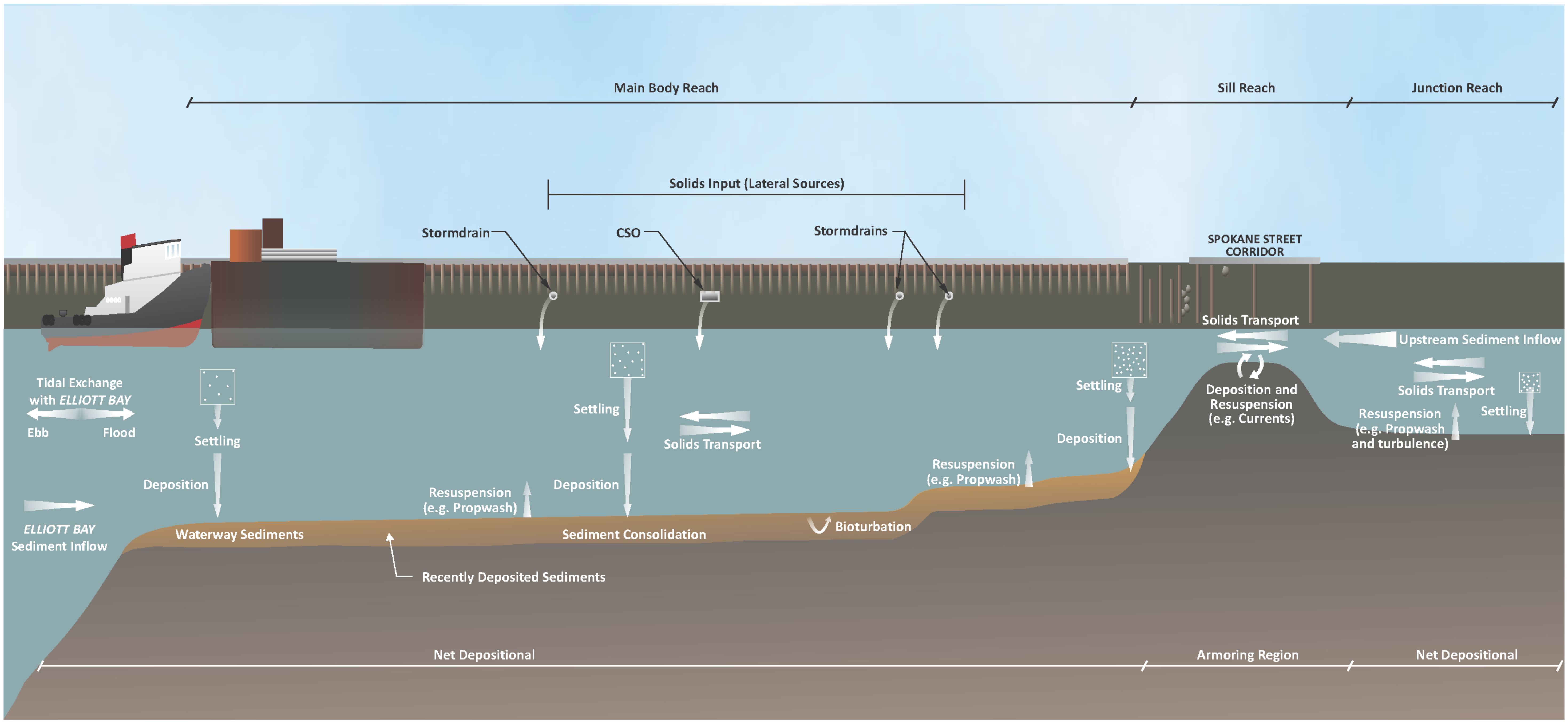
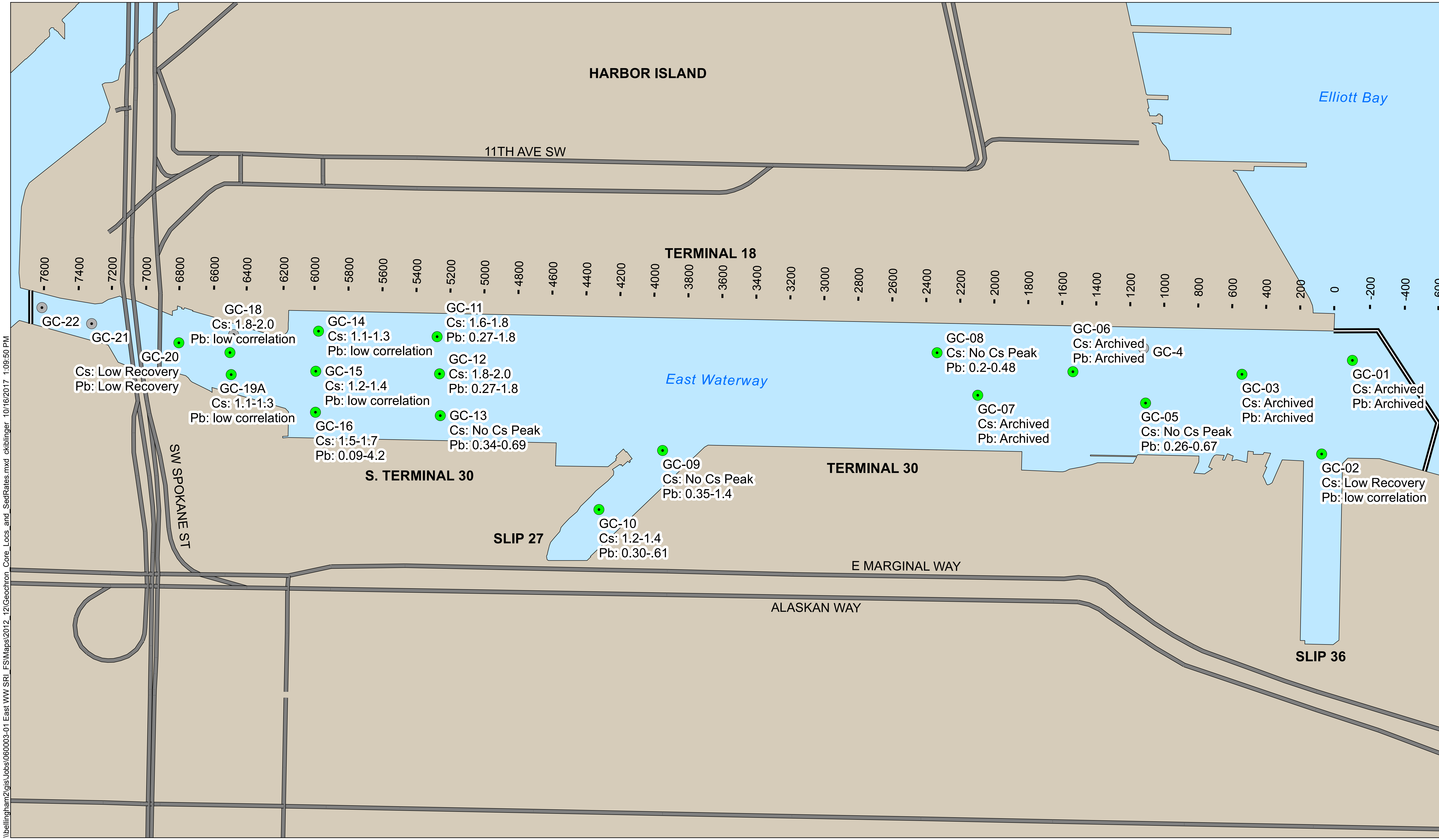


Figure 2-12
Conceptual Summary of Sediment Transport in East Waterway
Feasibility Study
East Waterway Study Area

\\fuji\anchor\Projects\Port of Seattle\060003-01 East WW SRI_FS\FS\Section 1-4\figures\Round 3 Figures\Figure 2-12 source files\Figure 2-12.docx



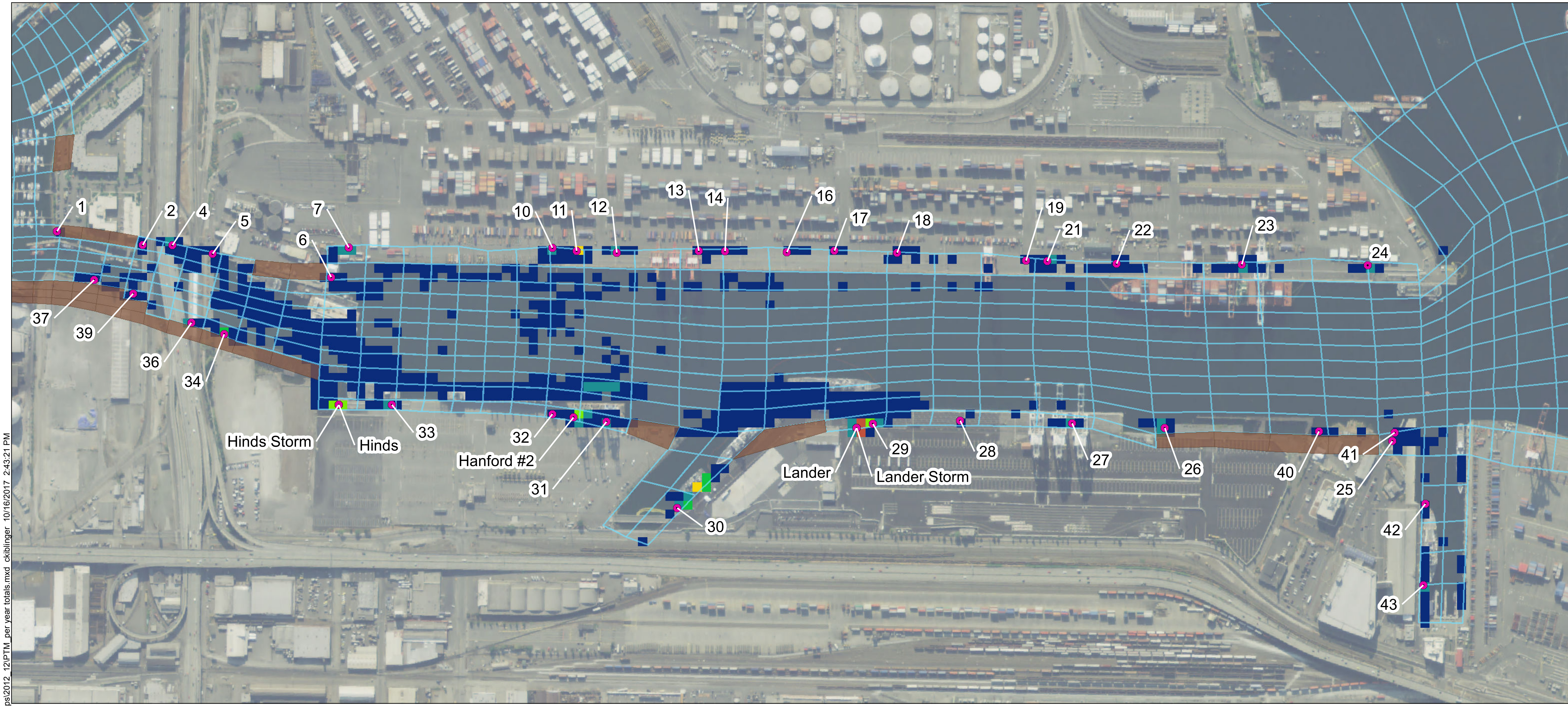
Geochronological Cores - Collected

Geochronological Cores - No Recovery

NOTE:
1. Rates are cm/yr.
2. Presented locations represent accepted at or final attempt.
3. Cs = Cesium - 137
4. Pb = Lead - 210

0 250 500 750 1,000
Feet

Figure 2-13
Geochronological Core Locations and Sedimentation Rates
Feasibility Study
East Waterway Study Area



PTM Outfall Locations

EFDC Hydrodynamic Model Grid

Land

Water

Deposition, cm/year

0 - 0.1
0.11 - 0.25
0.26 - 0.5
0.51 - 0.75
0.76 - 1
1.01 - 2
2.01 - 2.47

Feet

0 250 500 750 1,000

NOTES:

1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation per square foot (lb/sq foot)
2. Mass accumulation represents deposition over one year (extrapolated from a 28 day simulation time).
4. Lander, Hanford, and Hines are CSOs.
5. Outfall numbers (names) correspond to drainage basins.
6. Deposition pattern shown does not account for re-suspension of particles due to prop wash.

Figure 2-14

Predicted Annual Deposition (cm/yr) due to Lateral Loads, Base Case Current Conditions

Feasibility Study

East Waterway Study Area

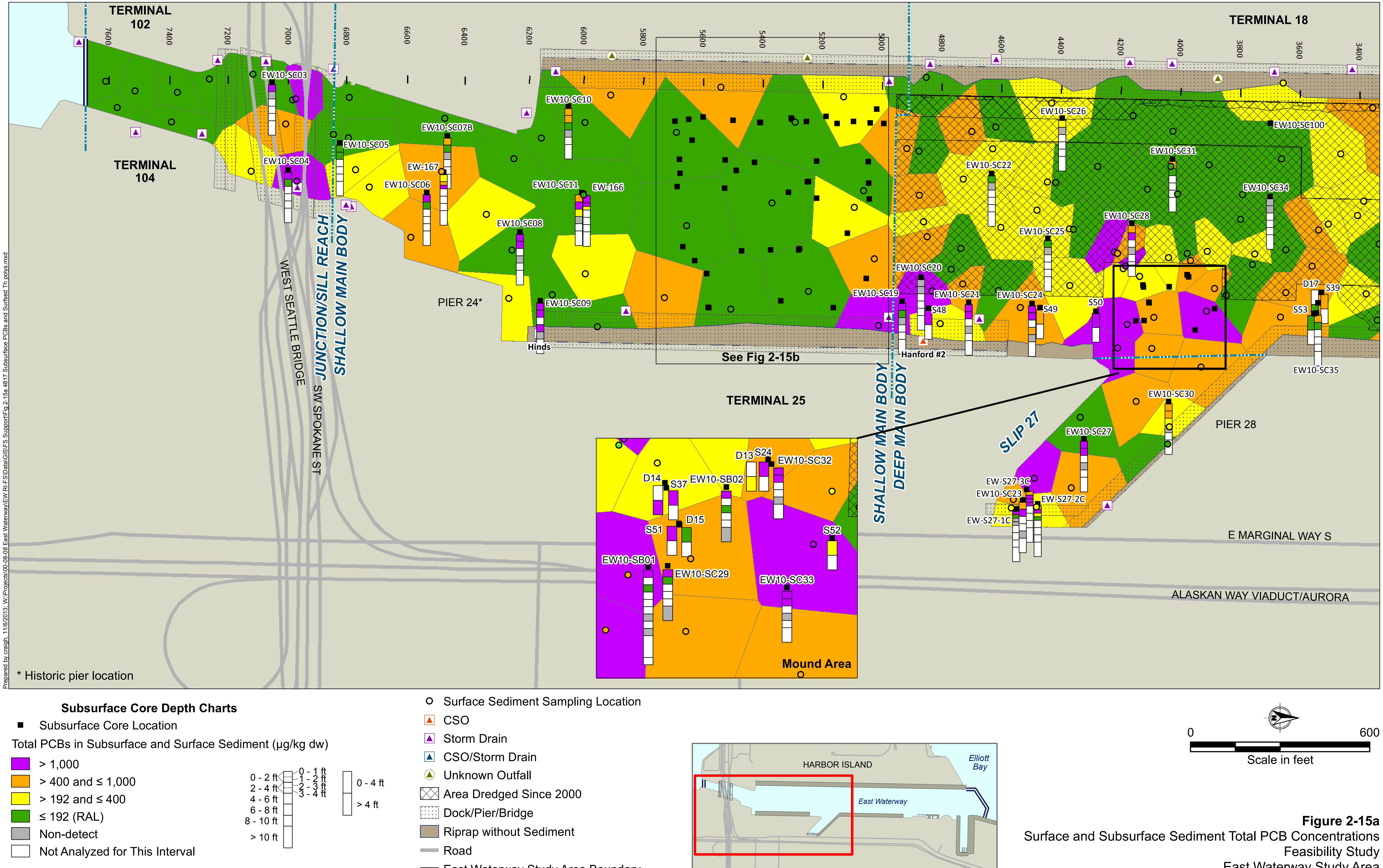
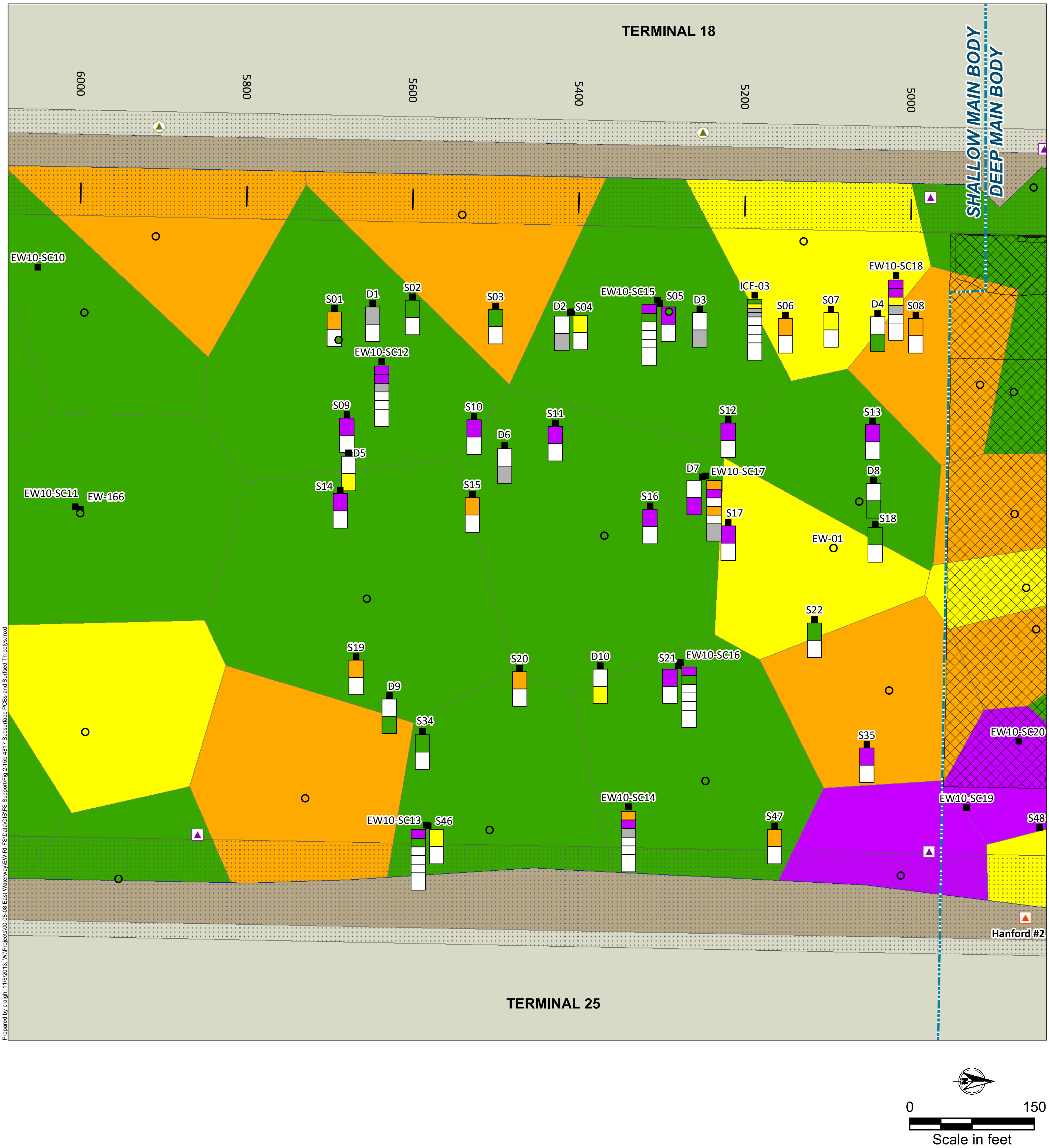


Figure 2-15a
Surface and Subsurface Sediment Total PCB Concentrations
Feasibility Study
East Waterway Study Area

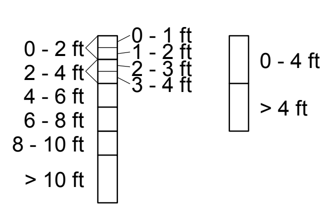


Subsurface Core Depth Charts

■ Subsurface Core Location

Total PCBs in Subsurface and Surface Sediment (µg/kg dw)

- > 1,000
- > 400 and ≤ 1,000
- > 192 and ≤ 400
- ≤ 192 (RAL)
- Non-detect
- Not Analyzed for This Interval



- Surface Sediment Sampling Location
- Area Dredged Since 200
- Dock/Pier/Bridge
- Riprap without Sediment
- CSO
- CSO/Storm Drain
- Storm Drain
- Unknown
- East Waterway Study Area Boundary

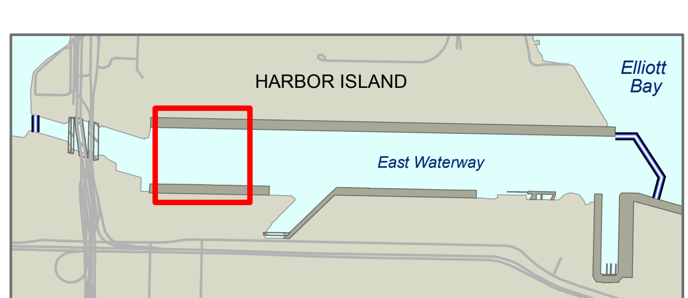
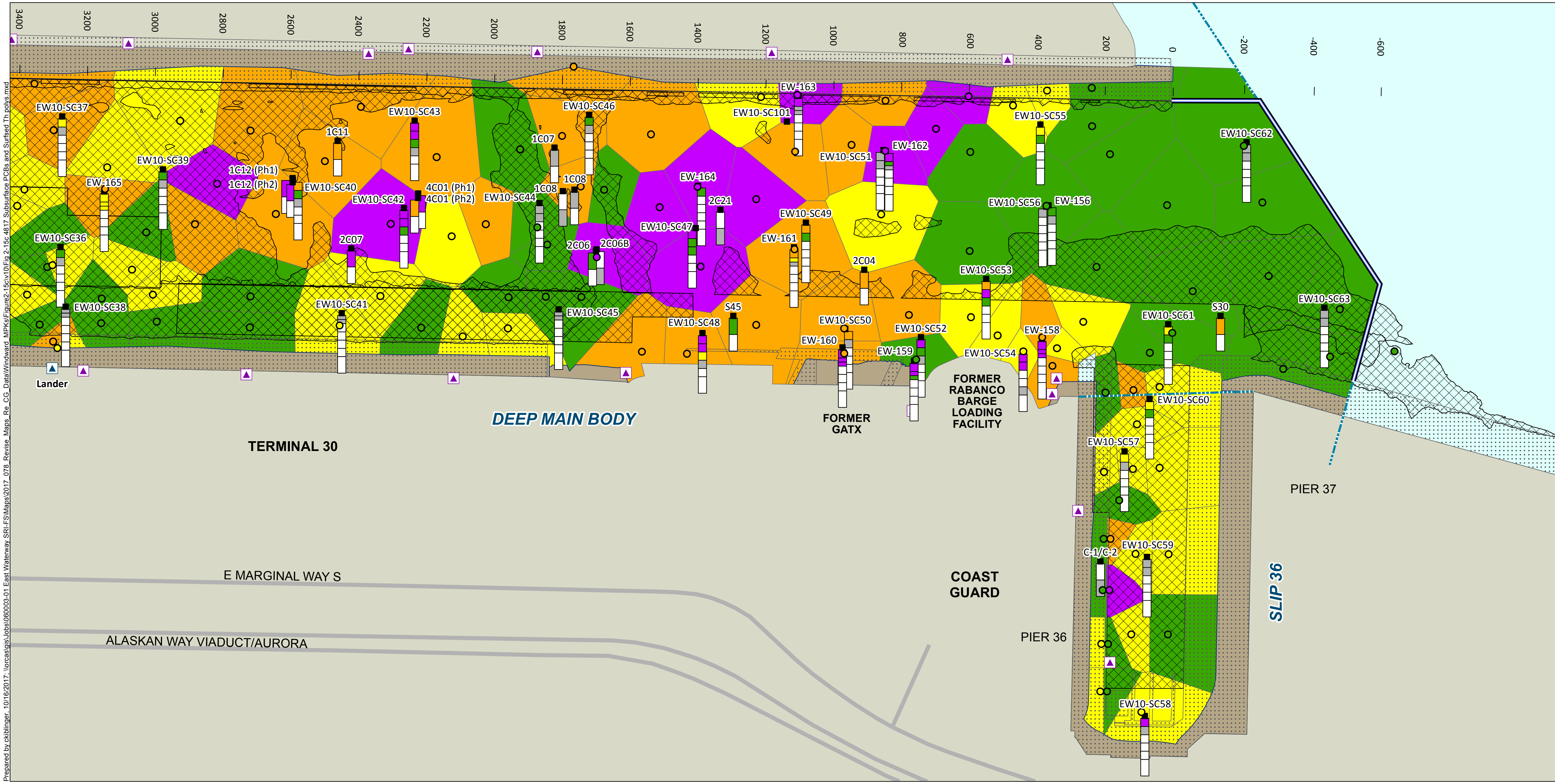


Figure 2-15b
Surface and Subsurface Sediment
Total PCB Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

Total PCBs in Subsurface and Surface Sediment (µg/kg dw)

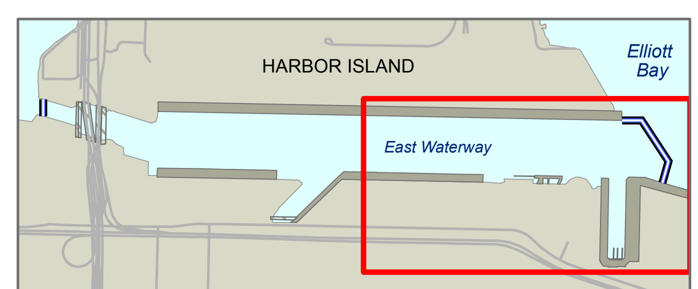
- > 1,000
- > 400 and ≤ 1,000
- > 192 and ≤ 400
- ≤ 192 (RAL)
- Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

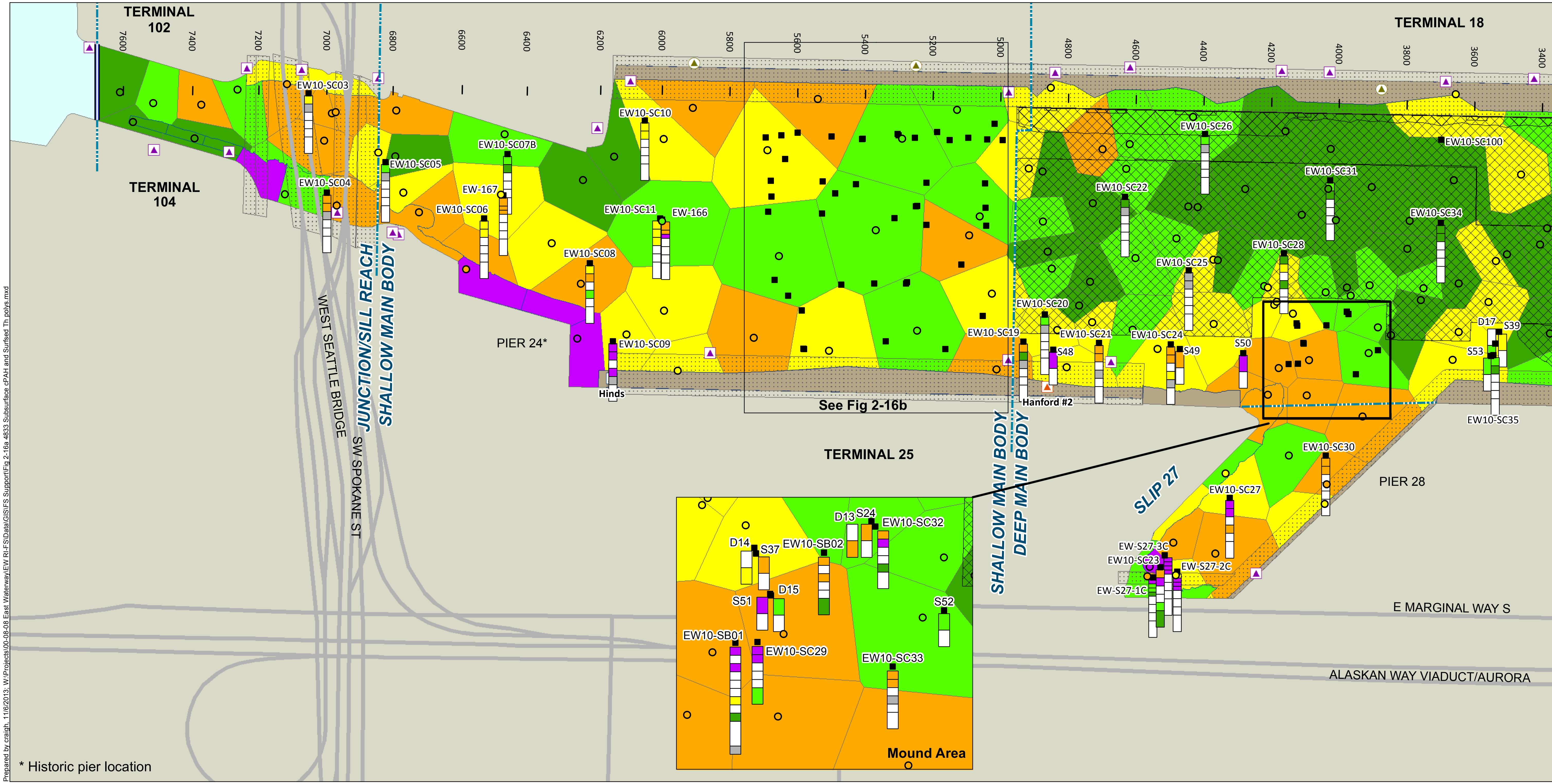
0 - 4 ft, > 4 ft

- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary



0 600
Scale in feet

Figure 2-15c
Surface and Subsurface Sediment Total PCB Concentrations
Feasibility Study
East Waterway Study Area



Prepared by craigh, 11/6/2013; W:\Projects\00-08-08 East Waterway\EW RI-FS\Data\GIS\FS Support\Fig 2-16a 4833 Subsurface cPAH and Surfsed Th polys.mxd

Subsurface Core Depth Charts

■ Subsurface Core Location

cPAH in Subsurface and Surface Sediment (µg TEQ/kg dw)[a]

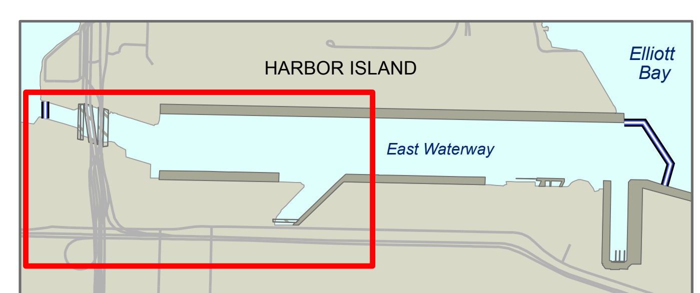
- > 1,200 (> 95th percentile)
- > 480 and ≤ 1,200 (≤ 95th percentile)
- > 220 and ≤ 480 (≤ 75th percentile)
- > 95 and ≤ 220 (≤ 50th percentile)
- ≤ 95 (≤ 25th percentile)
- Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

0 - 4 ft, > 4 ft

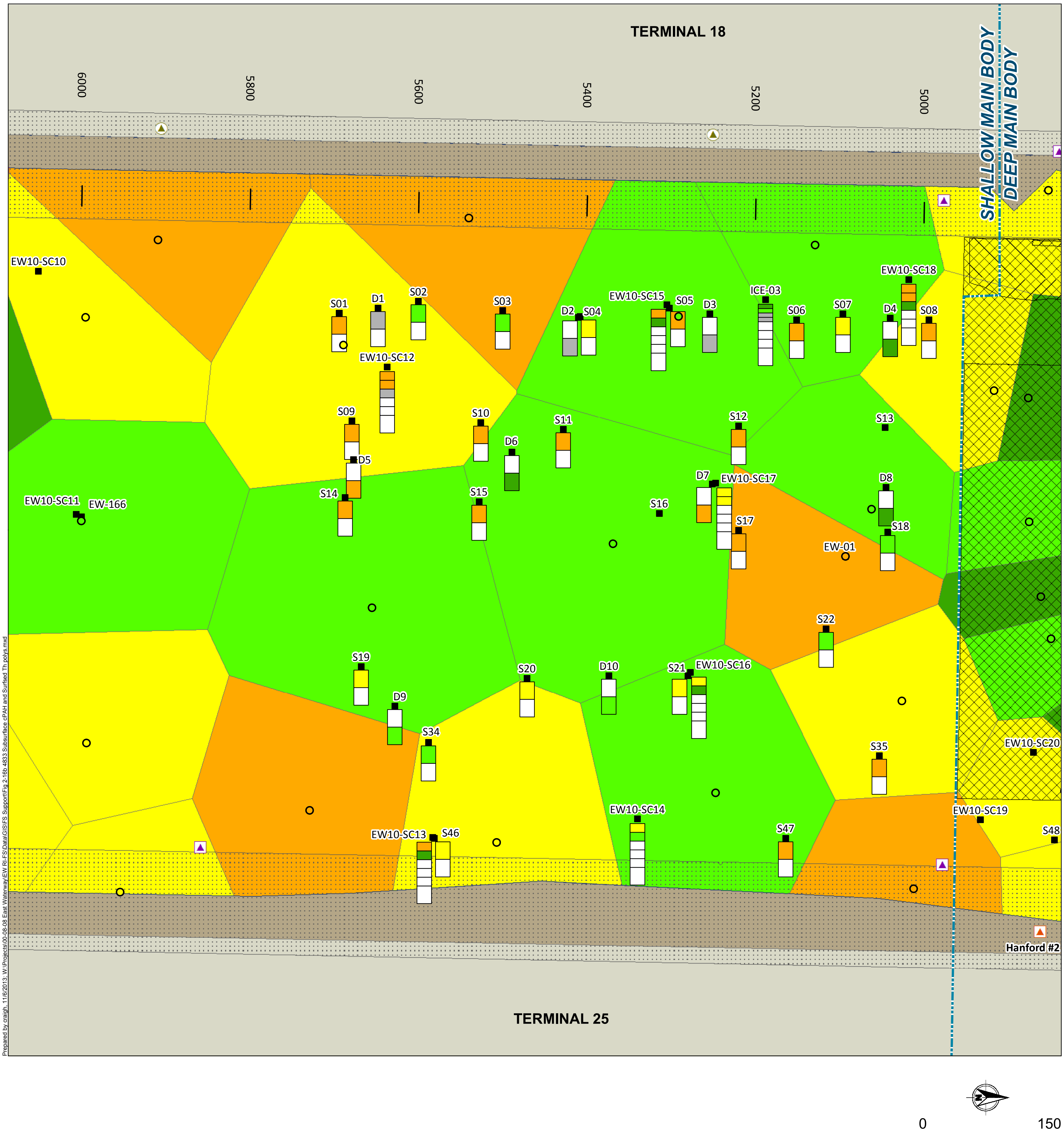
- Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary



0 600
Scale in feet

[a] Gray border = surface sediment Thiessen polygon extrapolation; blue border = MIS composite sample extrapolation.
The percentiles are all numeric percentiles of the surface sediment dataset.

Figure 2-16a
Surface and Subsurface Sediment cPAH Concentrations
Feasibility Study
East Waterway Study Area

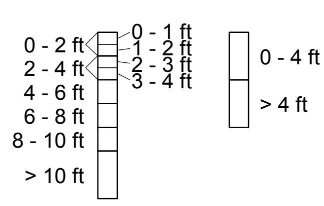


Subsurface Core Depth Charts

■ Subsurface Core Location

cPAH in Subsurface and Surface Sediment (µg TEQ/kg dw)

- > 1,200 (> 95th percentile)
- > 480 and ≤ 1,200 (≤ 95th percentile)
- > 220 and ≤ 480 (≤ 75th percentile)
- > 95 and ≤ 220 (≤ 50th percentile)
- ≤ 95 (≤ 25th percentile)
- Non-detect
- Not Analyzed for This Interval



The percentiles are all numeric percentiles of the surface sediment dataset.

- ○ Surface Sediment Sampling Location
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- CSO
- CSO/Storm Drain
- Storm Drain
- Unknown
- East Waterway Study Area Boundary

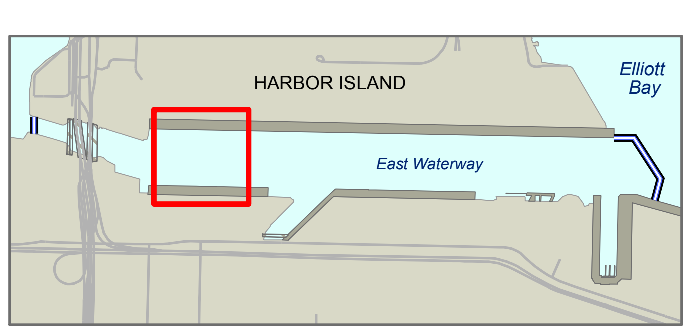
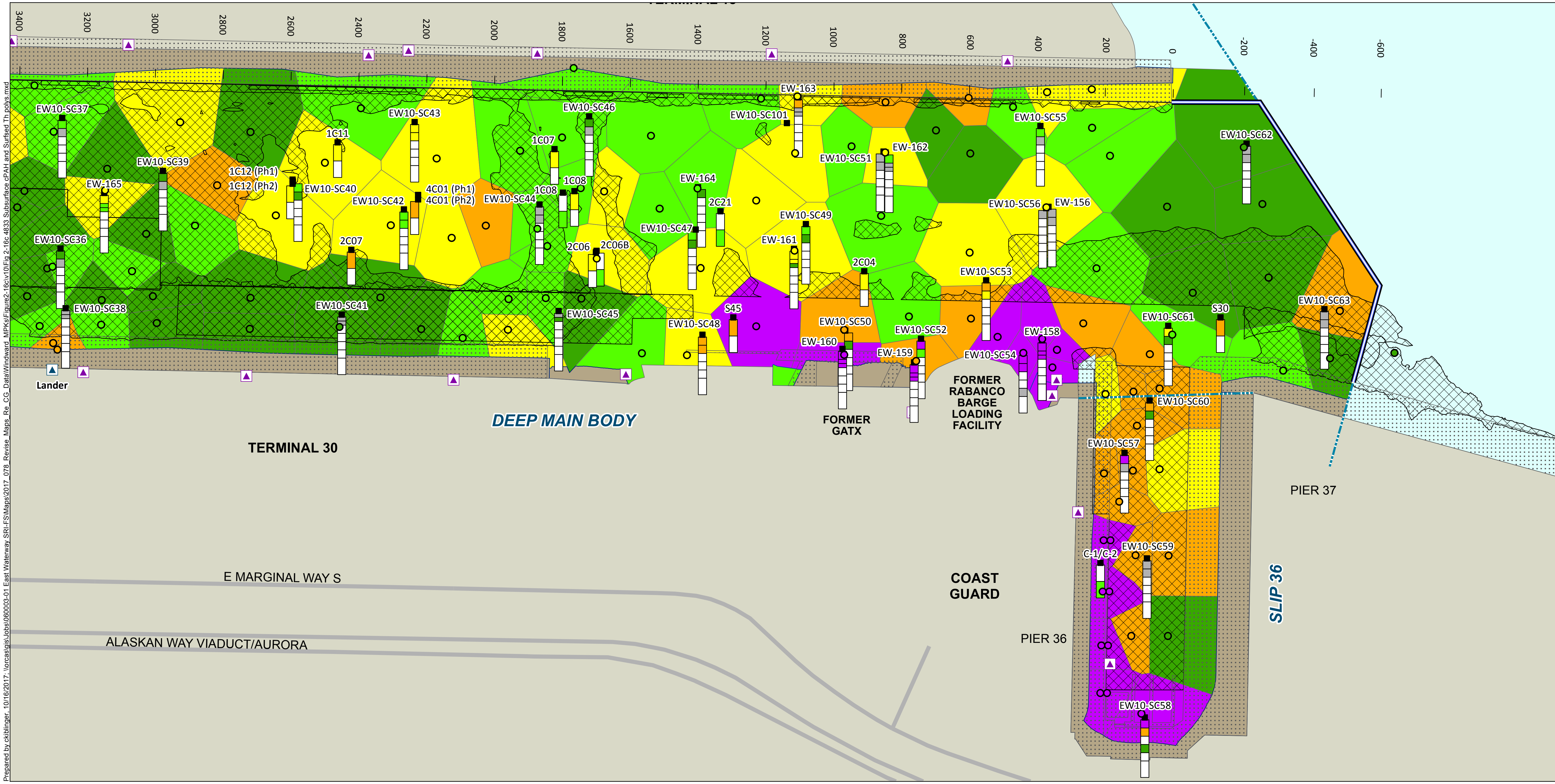


Figure 2-16b
Surface and Subsurface Sediment cPAH Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

cPAH in Subsurface and Surface Sediment (µg TEQ/kg dw)[a]

- > 1,200 (> 95th percentile)
- > 480 and ≤ 1,200 (≤ 95th percentile)
- > 220 and ≤ 480 (≤ 75th percentile)
- > 95 and ≤ 220 (≤ 50th percentile)
- ≤ 95 (≤ 25th percentile)
- Non-detect
- Not Analyzed for This Interval

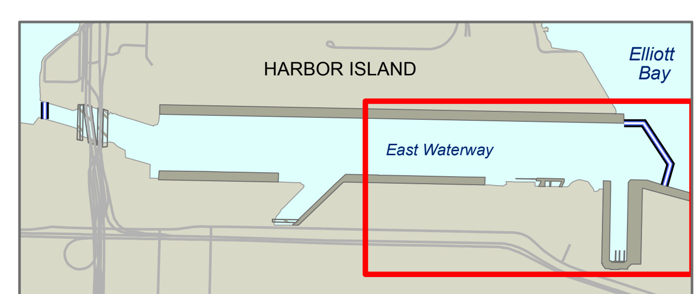
0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

0 - 4 ft, > 4 ft

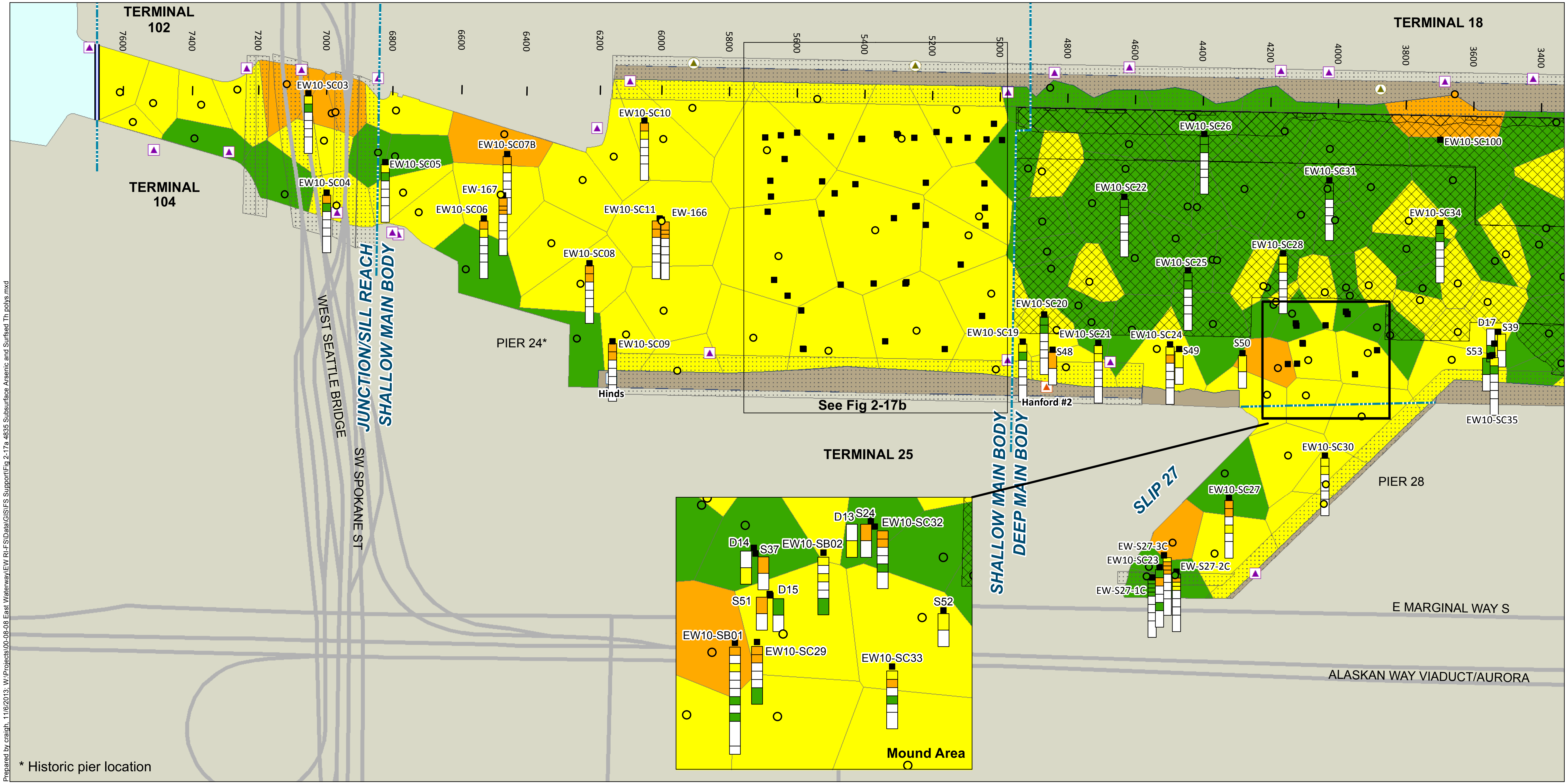
- Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary

[a] Gray border = surface sediment Thiessen polygon extrapolation; blue border = MIS composite sample extrapolation.



0 600
Scale in feet

Figure 2-16c
Surface and Subsurface Sediment cPAH Concentrations
Feasibility Study
East Waterway Study Area



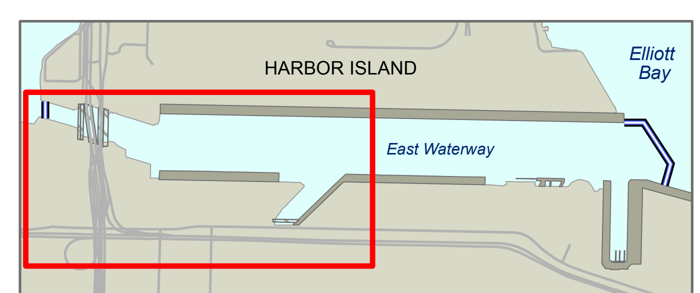
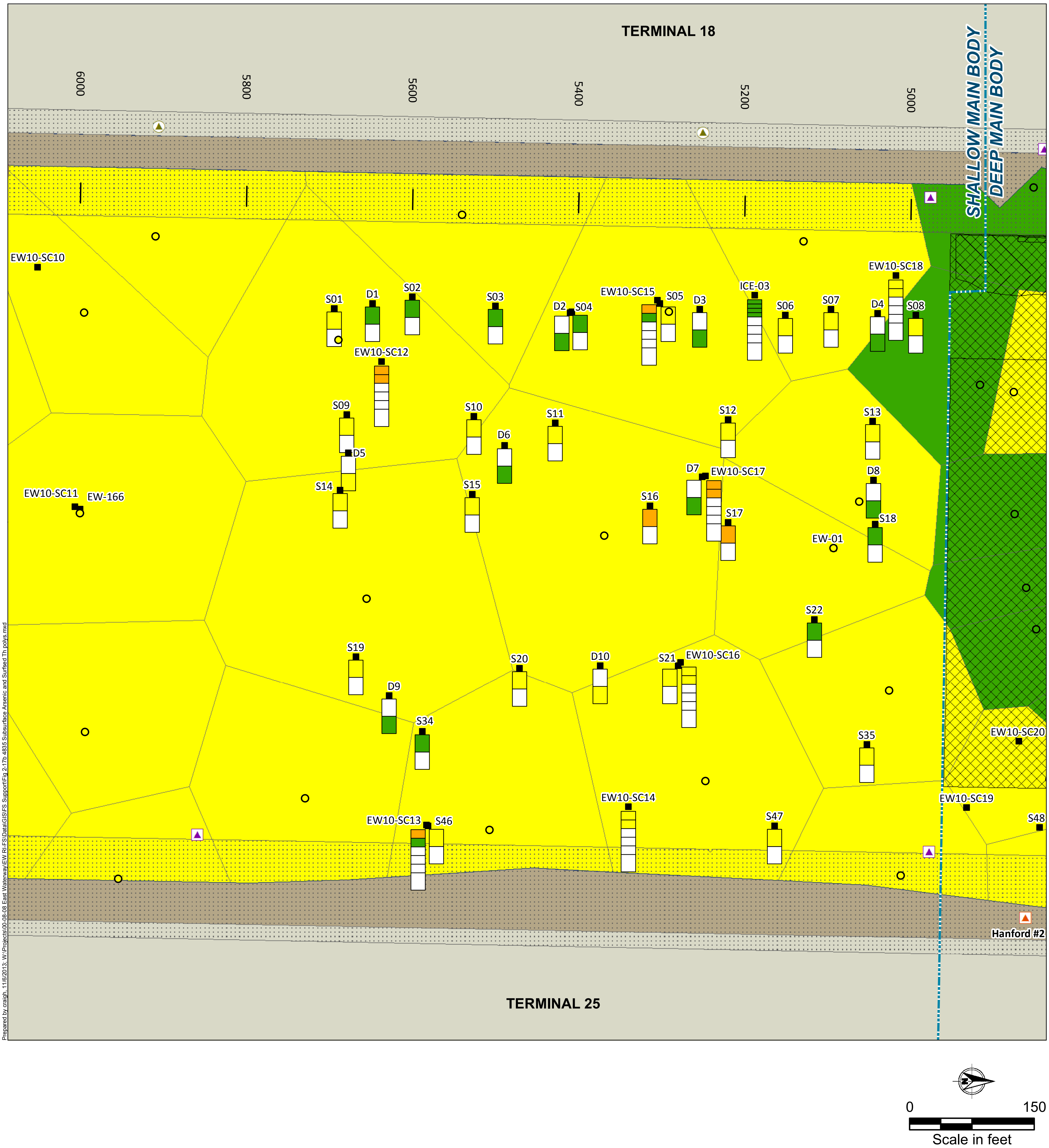


Figure 2-17a
Surface and Subsurface Sediment Arsenic Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

Arsenic in Subsurface and Surface Sediment (mg/kg dw)

- > 57 (> SQS)
- > 15 and ≤ 57 (≤ SQS)
- > 7.0 and ≤ 15
- ≤ 7.0
- Non-detect
- Not Analyzed for This Interval

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft; 0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft; 0 - 4 ft, > 4 ft

- ○ Surface Sediment Sampling Location
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- CSO
- CSO/Storm Drain
- Storm Drain
- Unknown
- East Waterway Study Area Boundary

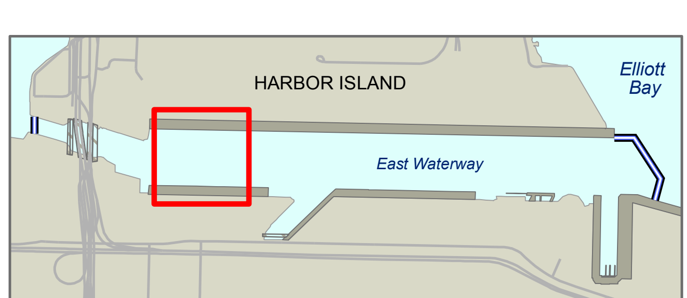
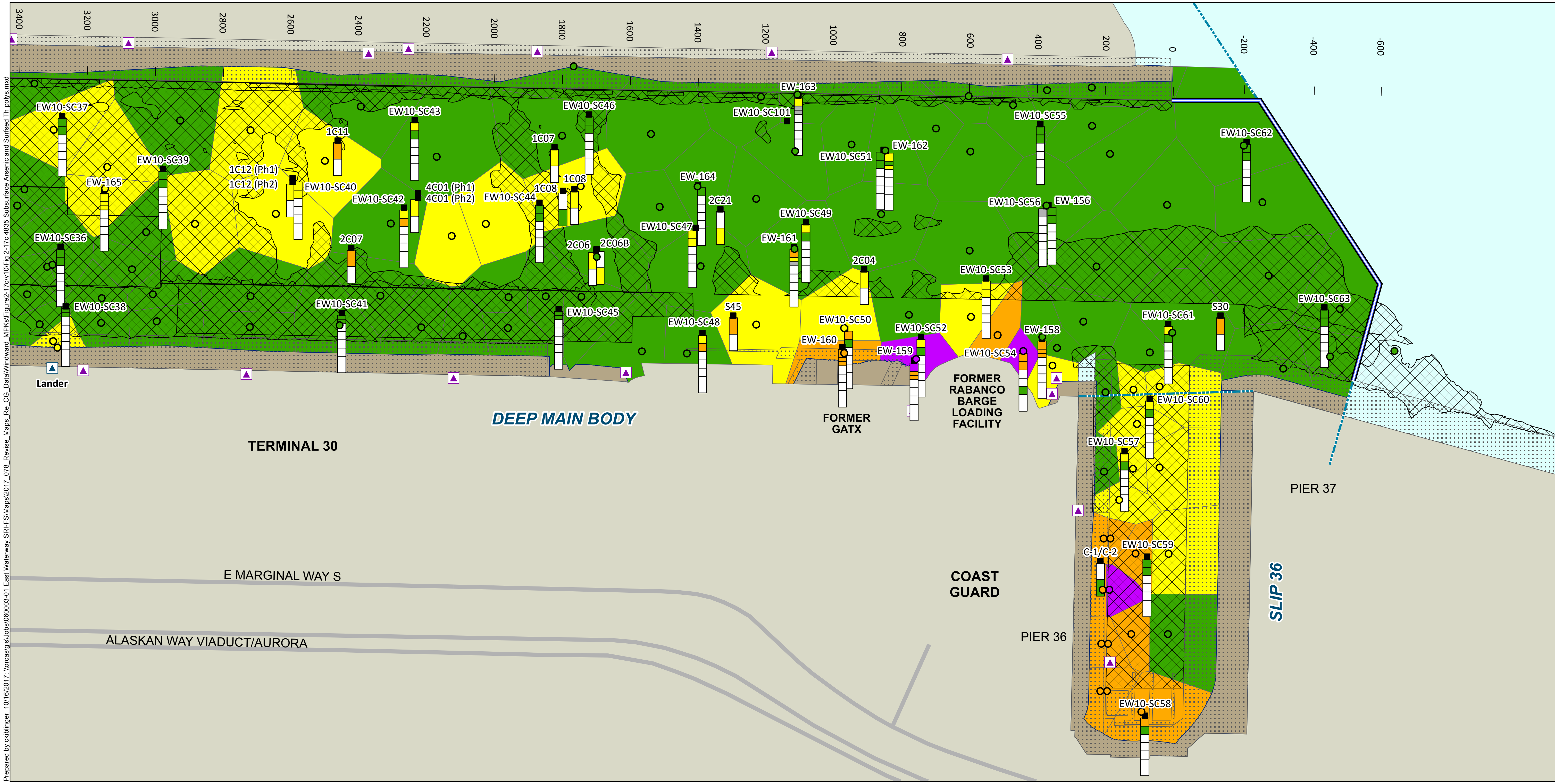


Figure 2-17b
Surface and Subsurface Sediment
Arsenic Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

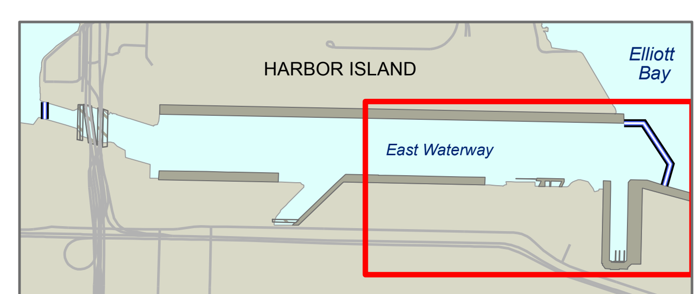
■ Subsurface Core Location

Arsenic in Subsurface and Surface Sediment (mg/kg dw)

- > 57 (> SQS)
- > 15 and ≤ 57 (≤ SQS)
- > 7.0 and ≤ 15
- ≤ 7.0
- Non-detect
- Not Analyzed for This Interval

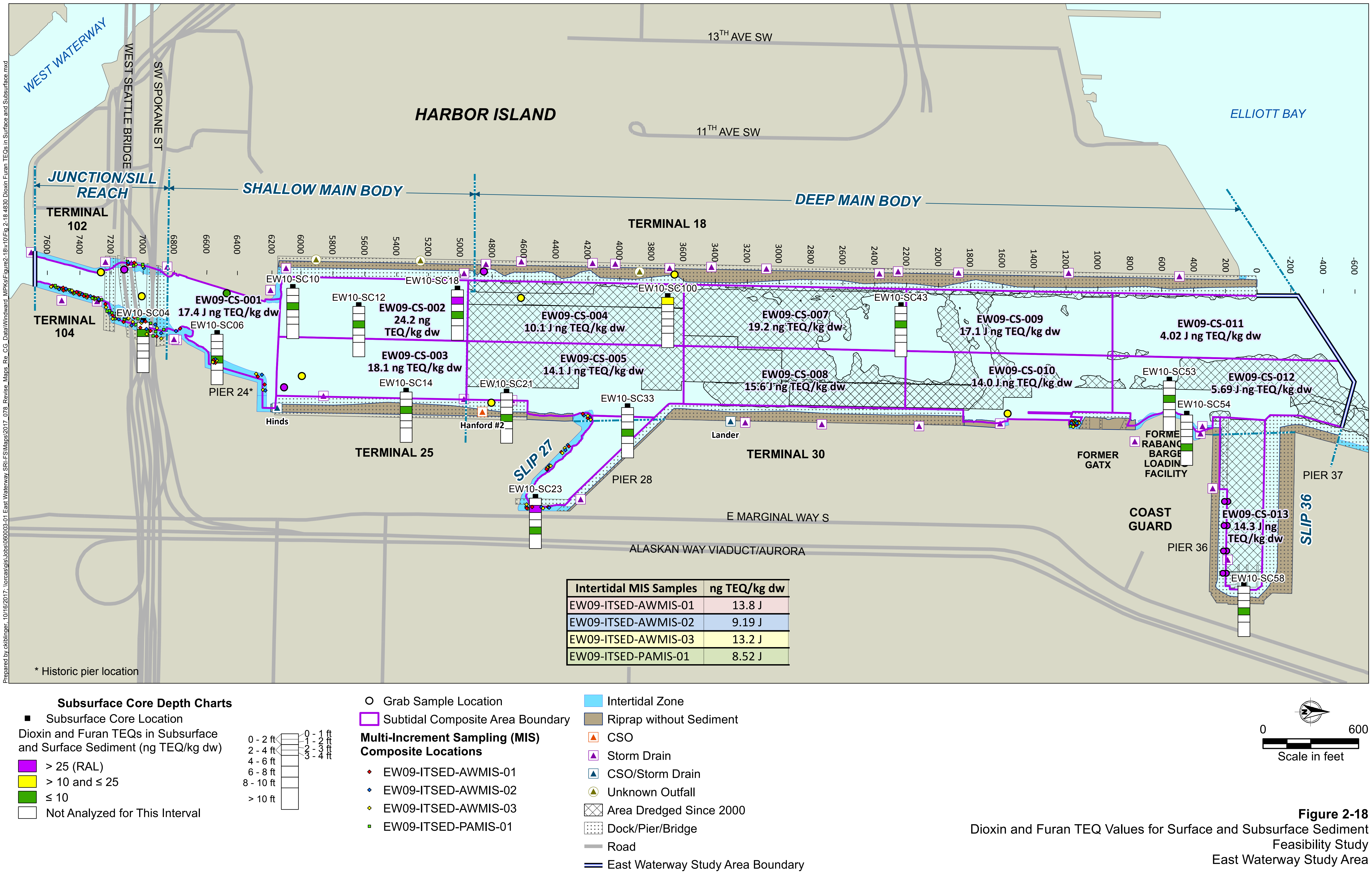
0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft; 0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft; 0 - 4 ft, > 4 ft

- Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary



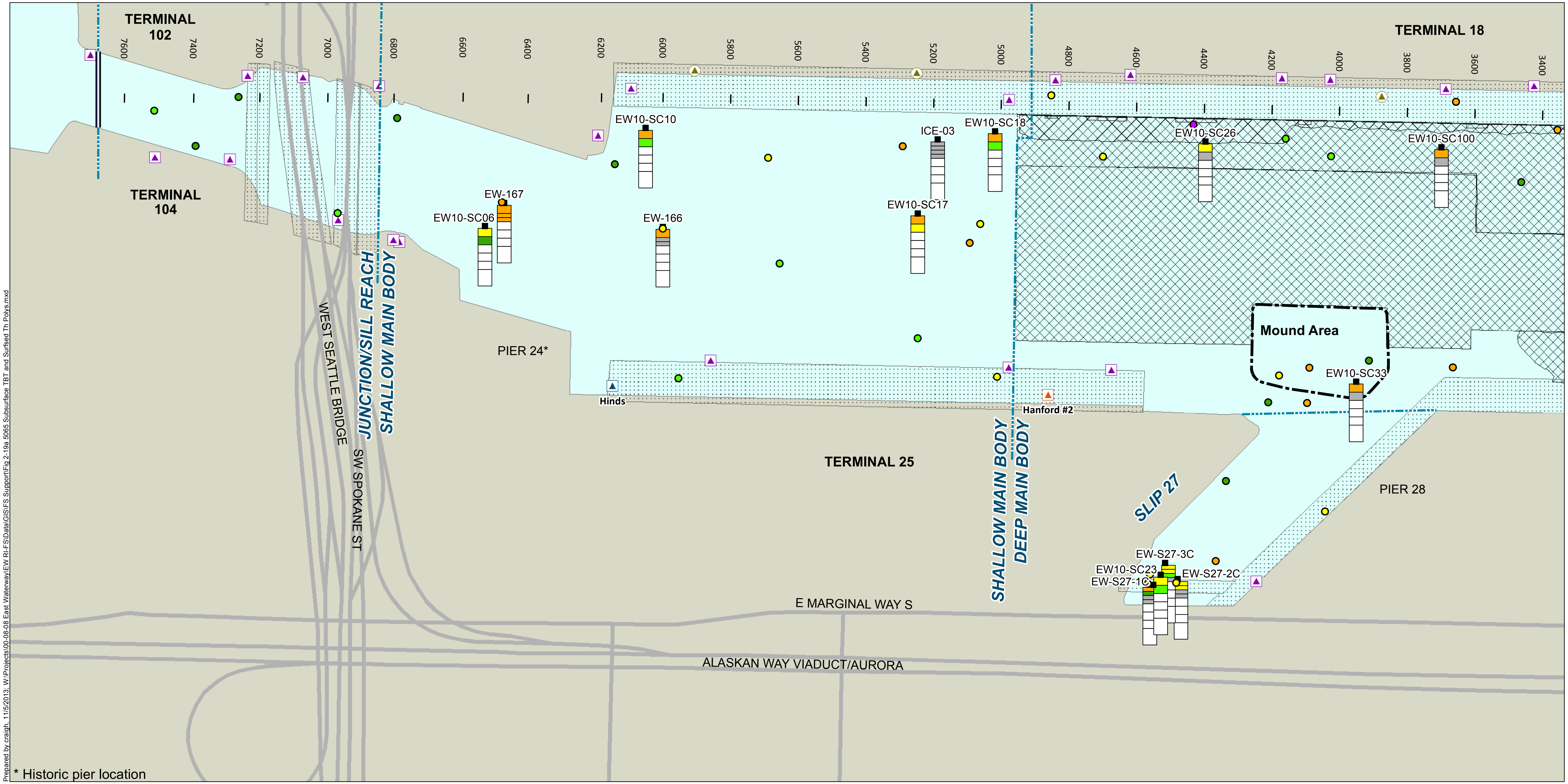
0 600
Scale in feet

Figure 2-17c
Surface and Subsurface Sediment Arsenic Concentrations
Feasibility Study
East Waterway Study Area



Intertidal MIS Samples	ng TEQ/kg dw
EW09-ITSED-AWMIS-01	13.8 J
EW09-ITSED-AWMIS-02	9.19 J
EW09-ITSED-AWMIS-03	13.2 J
EW09-ITSED-PAMIS-01	8.52 J

Figure 2-18
Dioxin and Furan TEQ Values for Surface and Subsurface Sediment
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

TBT in Subsurface and Surface Sediment (µg/kg dw)

- > 560 (> 95th percentile)
- > 79 and ≤ 560 (≤ 95th percentile)
- > 31 and ≤ 79 (≤ 75th percentile)
- > 10 and ≤ 31 (≤ 50th percentile)
- ≤ 10 (≤ 25th percentile)
- Non-detect
- Not Analyzed for This Interval

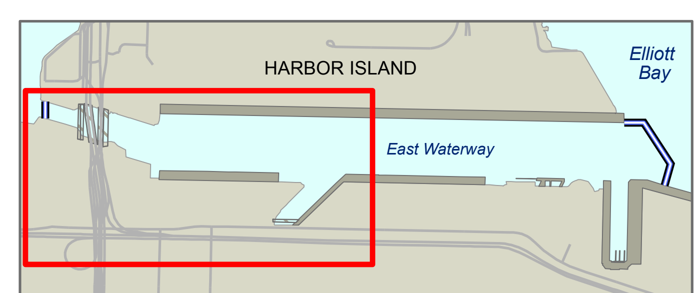
0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

0 - 4 ft, > 4 ft

The percentiles are all numeric percentiles of the surface sediment dataset.

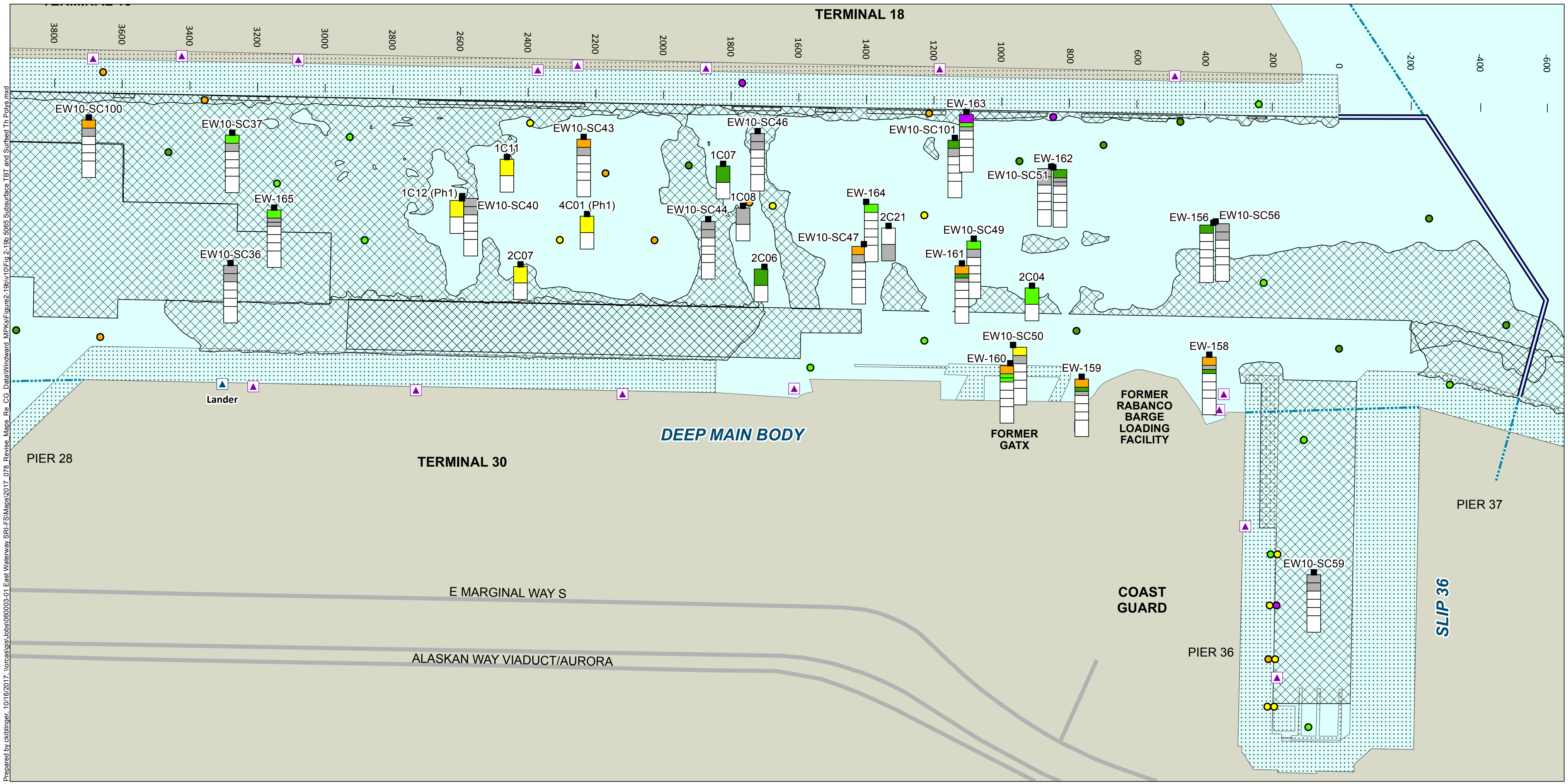
- Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Road
- East Waterway Study Area Boundary

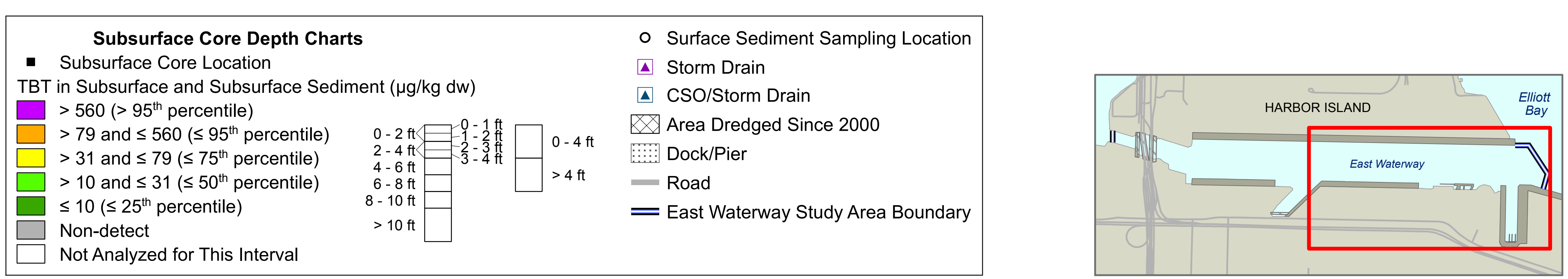


0 600
Scale in feet

Figure 2-19a
Surface and Subsurface Sediment TBT Concentrations
Feasibility Study
East Waterway Study Area

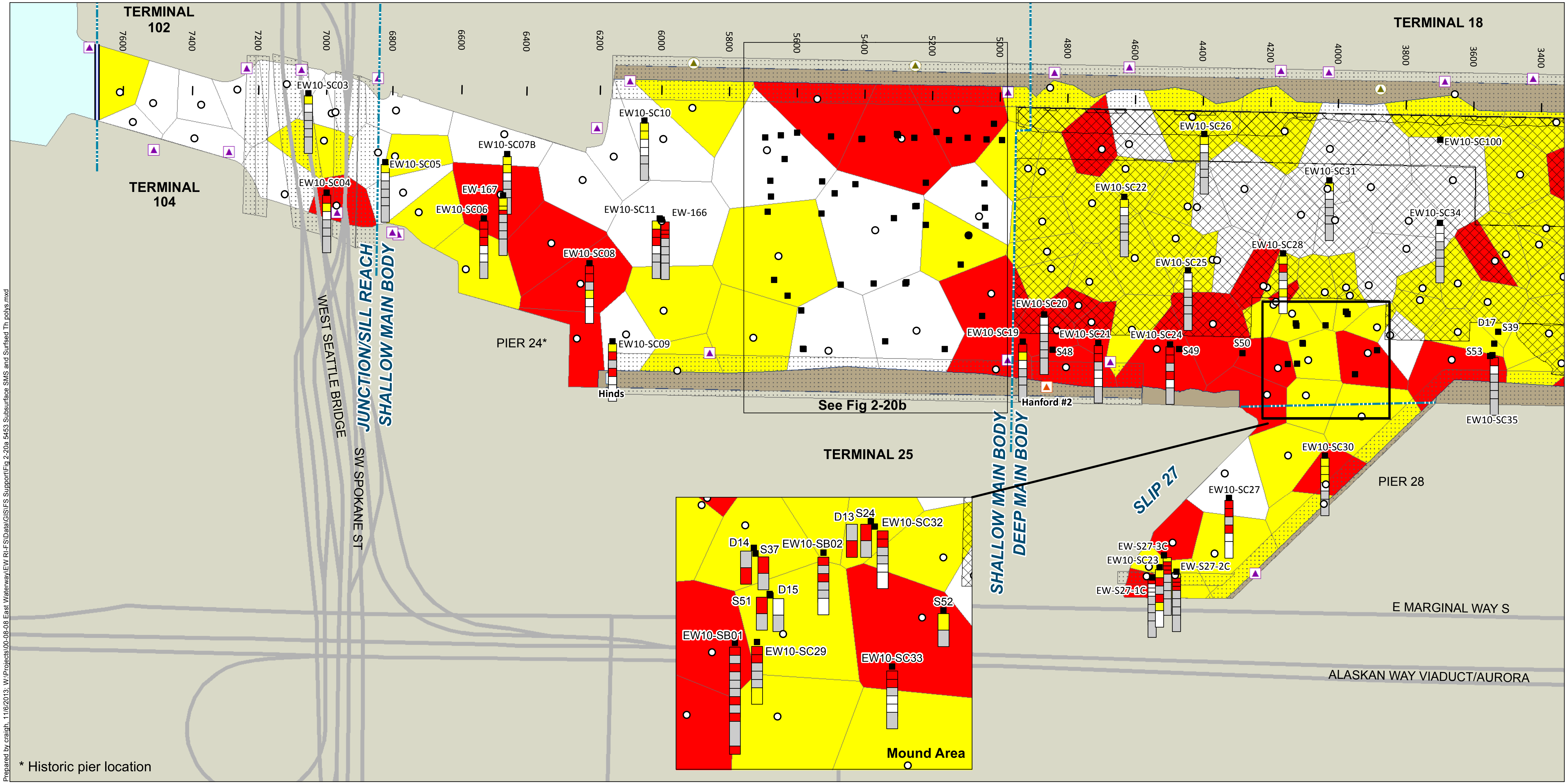
Prepared by craigh, 11/5/2013; W:\Projects\00-08-08 East Waterway\EW RI-FS\Data\GIS\FS Support\Fig 2-19a 5065 Subsurface TBT and Surfsed Th Polys.mxd





0 600
Scale in feet

Figure 2-19b
Surface and Subsurface Sediment TBT Concentrations
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

SMS Exceedance in Subsurface and Surface Sediment [a]

- > CSL, Detect
- > SQS and ≤ CSL, Detect
- ≤ SQS or Non-detect
- Not Analyzed for This Interval

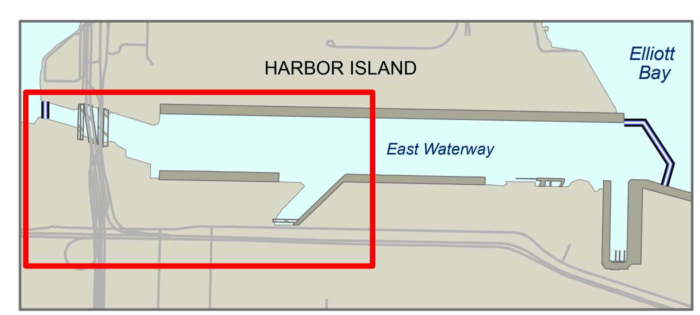
0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

0 - 4 ft, > 4 ft

- ○ Surface Sediment Sampling Location
- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary

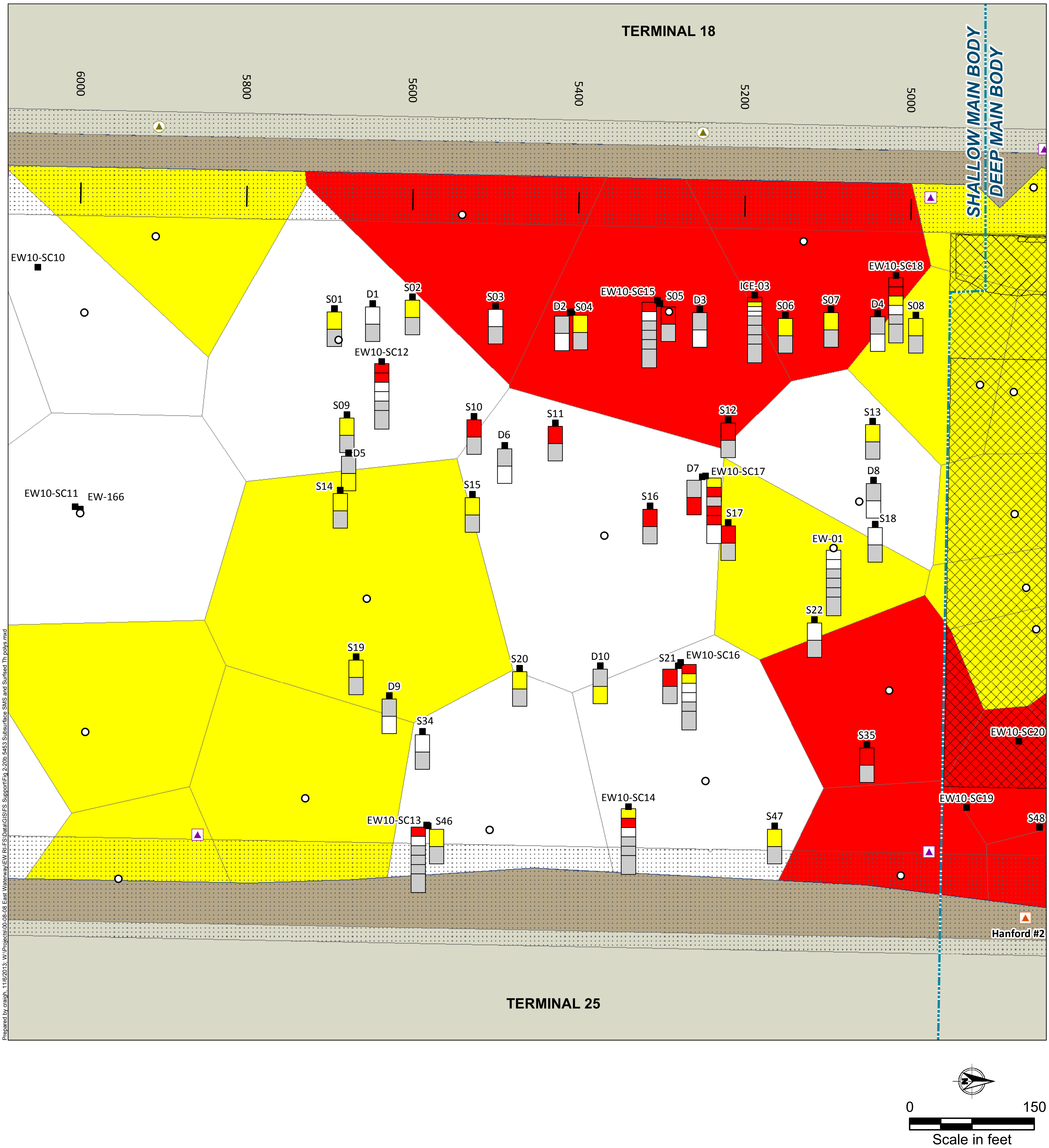
0 — 600
Scale in feet



[a] Thiessen polygons represent final SMS status (chemical criteria and toxicity combined) in surface sediment.

Figure 2-20a
Exceedances of SQS and CSL (Chemical Criteria and Toxicity Combined) Using Thiessen Polygons for the Surface Sediment Dataset
Feasibility Study
East Waterway Study Area

Prepared by craigh, 11/6/2013; W:\Projects\00-08-06 East Waterway\EW RI-FS\Data\GIS\FS Support\Fig 2-20a 5453 Subsurface SMS and Surfsed Th polys.mxd

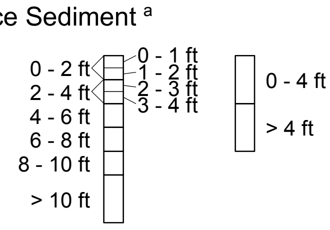


Subsurface Core Depth Charts

■ Subsurface Core Location

SMS Exceedance in Subsurface and Surface Sediment [a]

- > CSL, Detect
- > SQS and ≤ CSL, Detect
- ≤ SQS or Non-detect
- Not Analyzed for This Interval



[a] Thiessen polygons represent final SMS status (chemical criteria and toxicity combined) in surface sediment.

- ○ Surface Sediment Sampling Location
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- CSO
- CSO/Storm Drain
- Storm Drain
- Unknown
- East Waterway Study Area Boundary

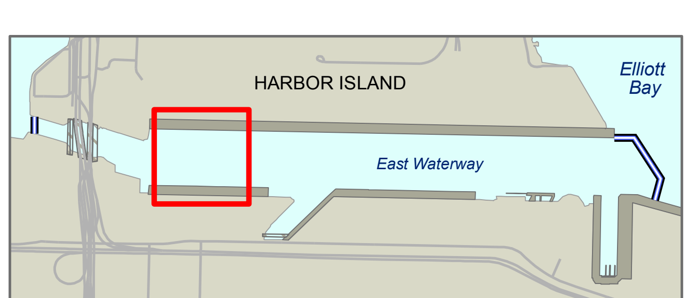
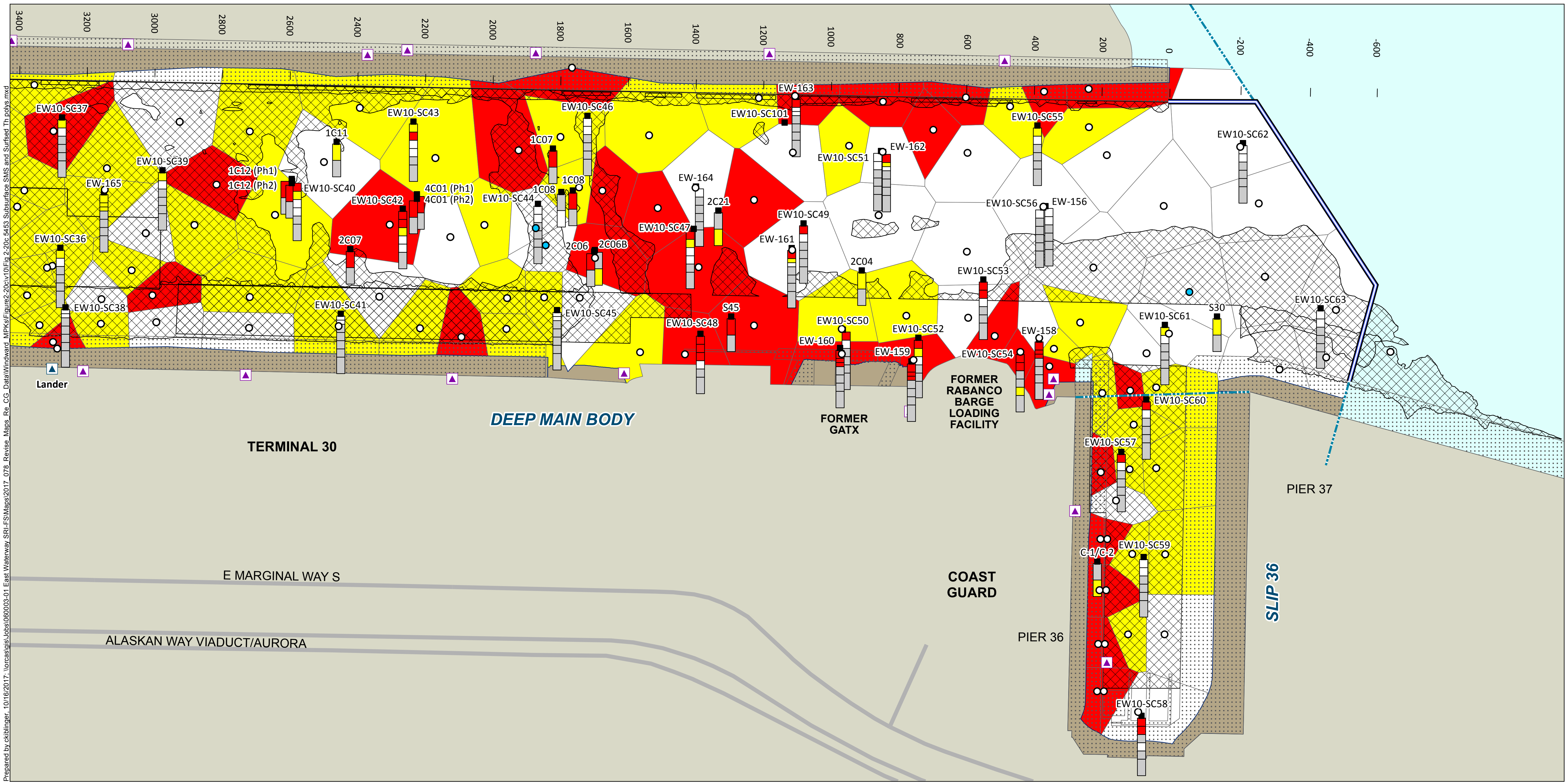


Figure 2-20b
Exceedances of SQS and CSL (Chemical Criteria and Toxicity Combined) Using Thiessen Polygons for the Surface Sediment Dataset
Feasibility Study
East Waterway Study Area



Subsurface Core Depth Charts

■ Subsurface Core Location

SMS Exceedance in Subsurface and Surface Sediment [a]

- > CSL, Detect
- > SQS and ≤ CSL, Detect
- ≤ SQS or Non-detect
- Not Analyzed for This Interval
- Surface Sediment Sampling Location
- Restricted Analyte Location[b]

0 - 2 ft, 2 - 4 ft, 4 - 6 ft, 6 - 8 ft, 8 - 10 ft, > 10 ft

0 - 1 ft, 1 - 2 ft, 2 - 3 ft, 3 - 4 ft

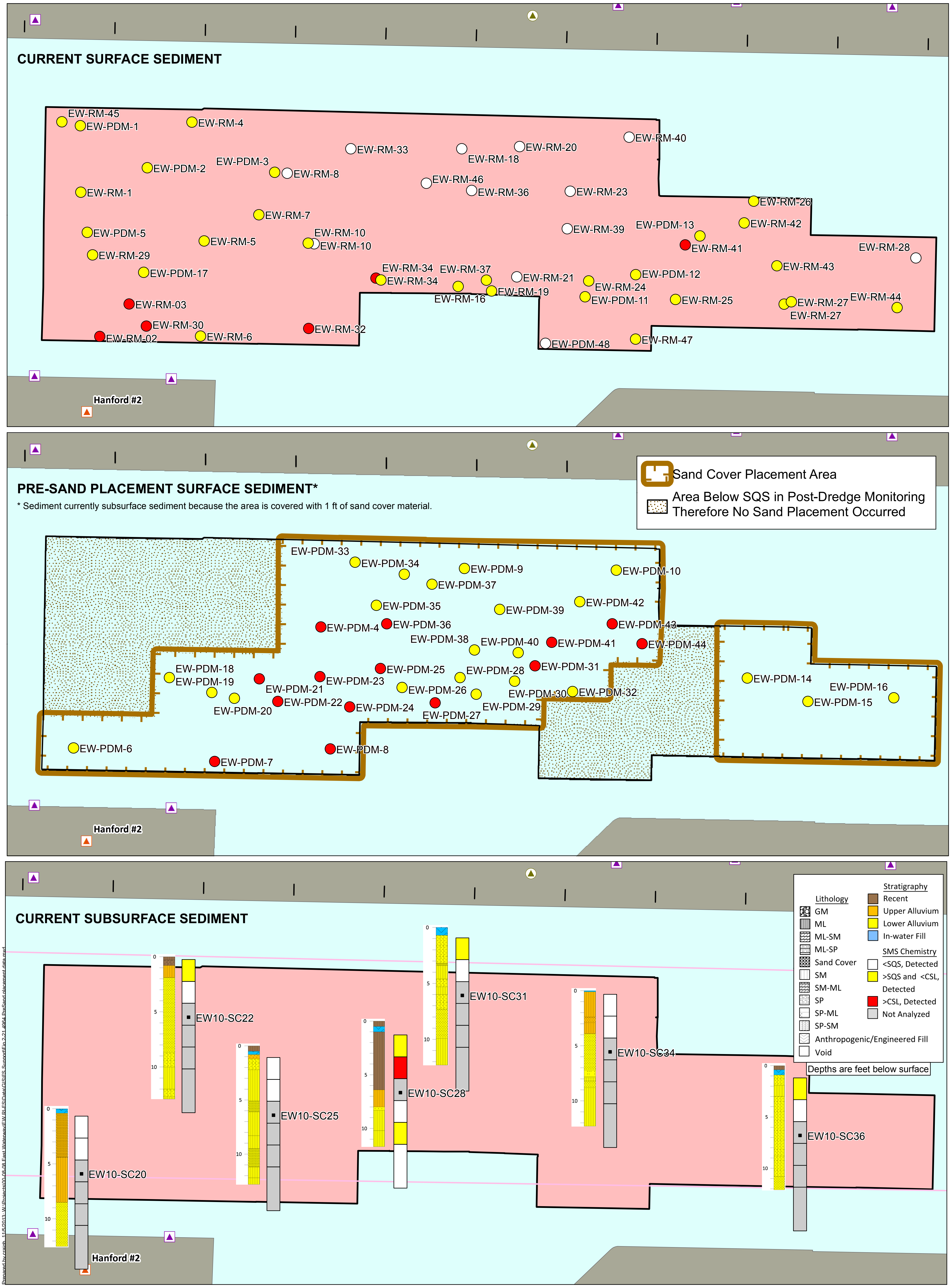
0 - 4 ft, > 4 ft

- CSO
- Storm Drain
- CSO/Storm Drain
- Unknown Outfall
- Area Dredged Since 2000
- Dock/Pier/Bridge
- Riprap without Sediment
- Road
- East Waterway Study Area Boundary

[a] Thiessen polygons represent final SMS status (chemical criteria and toxicity combined) in surface sediment.
[b] Not analyzed for SVOCs, phthalates, or metals other than mercury.

0 600
Scale in feet

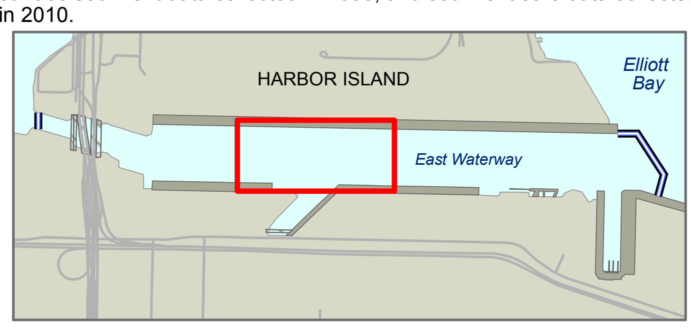
Figure 2-20c
Exceedances of SQS and CSL (Chemical Criteria and Toxicity Combined) Using Thiessen Polygons for the Surface Sediment Dataset
Feasibility Study
East Waterway Study Area



Surface Sediment SMS Status

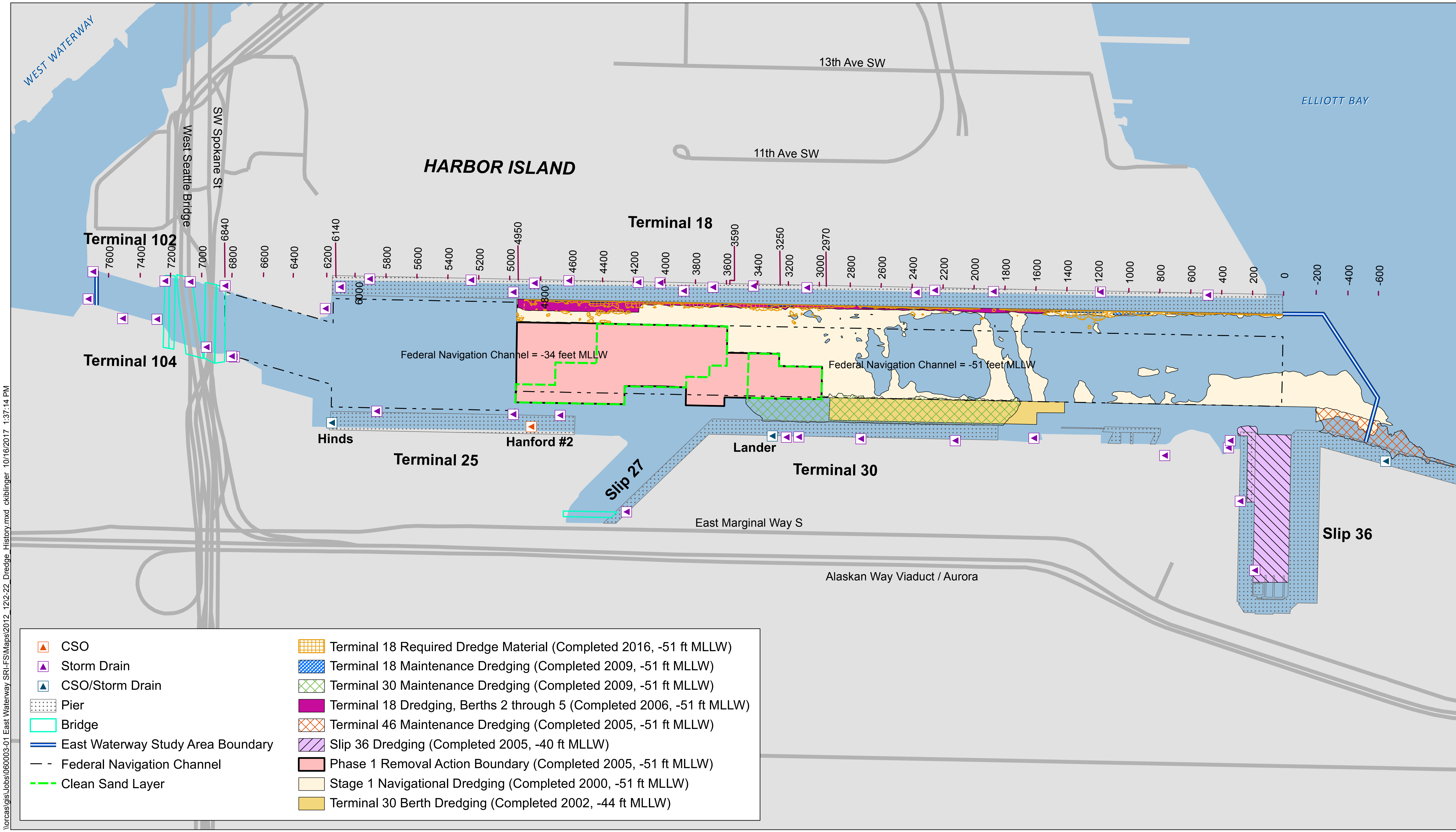
- > CSL, Detect
- > SQS and ≤ CSL, Detect
- ≤ SQS or Non-detect
- CSO
- Storm Drain
- Unknown Outfall
- Dock/Pier
- Phase 1 Removal Action Boundary

Note: Phase 1 data set consists of: post sand placement data collected for recontamination monitoring in 2006, 2007, and 2008; pre-sand placement surface sediment data collected in 2005; and sediment core data collected in 2010.



0 150
Scale in feet

Figure 2-21
Surface and Subsurface Sediment Datasets Associated with the Phase 1 Dredge Area
Feasibility Study
East Waterway Study Area



NOTES:

1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. Dredge activities listed indicate events since 2000.

0 300 600 900 1,200

Scale in Feet

Figure 2-22
Recent Dredge History
Feasibility Study
East Waterway Study Area

3 RISK ASSESSMENT SUMMARY

The baseline ERA (Windward 2012a) and baseline HHRA (Windward 2012b) were completed for the EW in 2012. This section summarizes the findings of both risk assessments, which are used in Section 4 of this FS to aid in establishing RAOs and PRGs.

The ERA (Windward 2012a) is discussed in Section 3.1, and presents the estimated risks for the benthic invertebrate community and for crabs, fish, and wildlife species. These receptors are exposed to contaminants in the EW primarily through contact with sediment and water, or through consumption of prey species found in the EW.

The HHRA (Windward 2012b) is discussed in Section 3.2, and presents the estimated risks for people who may be exposed to contaminants in the EW through consumption of resident seafood from the EW or through direct contact with sediment or water.

The RBTCs, discussed in Section 3.3, represent calculated sediment and tissue concentrations estimated to be protective of a particular receptor for a given exposure pathway and target risk level. RBTCs were derived in the SRI (Windward and Anchor QEA 2014) based on the baseline ERA (Windward 2012a) and HHRA (Windward 2012b). The RBTCs are also presented in this FS because they are used, along with other information, to establish PRGs in Section 4. Finally, this section concludes with a summary of the key findings from the risk assessments (Section 3.4).

3.1 Baseline Ecological Risk Assessment

The baseline ERA (Windward 2012a) estimated risks for ecological receptors in the EW that may be exposed to contaminants in sediment, surface water, porewater, and prey items.

Nine receptors of concern[19] were selected in the baseline ERA to be representative of groups of organisms in the EW with the same exposure pathways and that will be protective or

[19] Key considerations for selecting receptors of concern were the potential for direct or indirect exposure to sediment-associated contaminants, human and ecological significance, site use, sensitivity to COPCs at the site, susceptibility to biomagnification of COPCs, and data availability.

representative of other species that were not explicitly evaluated. These receptors of concern include the benthic invertebrate community; crabs; English sole, brown rockfish, and juvenile Chinook salmon (collectively discussed as "fish"); and pigeon guillemot, osprey, river otter, and harbor seal (collectively discussed as "wildlife species").

A conservative risk-based screening process first identified contaminants of potential concern (COPCs) for the ERA, which included a comparison of maximum contaminant concentrations with established criteria or literature-based toxicity reference values (TRVs; Windward 2012a). In this process, contaminant concentrations in sediment, surface water, porewater, and aquatic biota were compared to risk-based screening levels. Those contaminants present at concentrations above the screening levels or demonstrating the potential for unacceptable effects were identified as COPCs and underwent further risk analysis in the ERA as follows:

- Risks for the benthic community were estimated by comparing COPC concentrations in sediment with the numerical criteria of the Washington State SMS. Risks were also estimated based on site-specific sediment toxicity tests; a comparison of VOC concentrations in porewater to aquatic toxicity data; a comparison of PCB, mercury, and TBT concentrations in benthic invertebrate tissues to concentrations associated with adverse effects; and a comparison of COPC concentrations in surface water to marine WQC.
- Risks for fish and crabs were estimated by comparing COPC concentrations in fish and crab tissue with tissue residues associated with effects on survival, growth, or reproduction. In addition, risks for fish and crabs were estimated by comparing COPC concentrations in surface water to marine WQC.
- Risks for fish were also evaluated by comparing COPC concentrations[20] in fish diets (based on prey and sediment concentrations, or stomach content concentrations) to dietary concentrations that have been shown to cause adverse effects on survival, growth, or reproduction.
- For wildlife, risks were estimated based on calculations of daily doses of COPCs derived from the ingestion of sediment, water, and prey species. Risks were then

[20] This method was applied to metal and PAH COPCs.

estimated by comparing those doses with doses that have been shown to cause adverse effects on survival, growth, or reproduction.

Risks based on surface water, porewater, tissue, and dietary exposure were estimated by comparing COPC concentrations in the media of concern to WQC or TRVs, including no-observed-adverse-effect levels (NOAELs) and lowest-observed-adverse-effect levels (LOAELs). Risks were estimated by calculating hazard quotients (HQs) as the ratio of the COPC concentrations in the media of concern to the toxicity value as represented by SMS, WQC, or selected NOAELs and LOAELs. The risks estimated for each of these receptors are summarized in the following sections.

3.1.1 Benthic Invertebrate Community

Contaminant concentrations in surface sediments were compared to the SQS[21] and the CSL (WAC 173-204-320 and WAC 173-204-562, respectively) numerical chemical values of the SMS. Concentrations of total dichlorodiphenyl-trichloroethanes (DDTs) in surface sediment were compared with DMMP sediment quality guidelines because SMS values are not available for total DDTs. A contaminant was selected as a COC if its concentration was found to be above the SQS criteria (or above the DMMP guidelines in the case of total DDTs) in one or more sediment samples from the EW. Thirty contaminants were identified as COCs for the benthic invertebrate community based on surface sediment data (Table 3-1).

When contaminant concentrations in surface sediment exceed the SMS criteria, the potential exists for minor adverse effects on the benthic invertebrate community living in intertidal and subtidal sediment. The SQS were exceeded in approximately 61% (96 acres) of the EW study area. Of these 96 acres, a higher likelihood for minor adverse effects was identified in 36 acres, corresponding to approximately 23% of the EW, where contaminant concentrations or biological effects resulted in exceedances of the CSL of the SMS. The other 59 acres (38% of the EW) had contaminant concentrations or biological effects that exceeded the SQS but

[21] The revised SMS have changed the term SQS to sediment cleanup objective (SCO) in Section 204-562 of the WAC, but still uses the term SQS in Section 204-320 of the WAC. Therefore, the term SQS has been retained for this FS and is synonymous with "SCO based on protection of the benthic community" in the revised SMS.

Table 3-1
Summary of COCs and Selection of Risk Driver COCs for Benthic Invertebrates Based on Surface Sediment Exposure

COC	SMS Criteria			No. of Detected Concentrations in Surface Sediments		Risk Driver?
	Unit	SQS	CSL	> SQS, ≤ CSL	> CSL	
Metals						
Arsenic	mg/kg dw	57	93	0	3	Yes
Cadmium		5.1	6.7	1	1	Yes
Mercury		0.41	0.59	41	10	Yes
Zinc		410	960	4	2	Yes
PAHs						
2-Methylnaphthalene	mg/kg OC	38	64	0	3	Yes
Acenaphthene		16	57	11	13	Yes
Anthracene		220	1,200	5	2	Yes
Benzo(a)anthracene		110	270	7	7	Yes
Benzo(a)pyrene		99	210	7	8	Yes
Benzo(g,h,i)perylene		31	78	7	8	Yes
Total benzofluoranthenes		230	450	9	3	Yes
Chrysene		110	460	9	6	Yes
Dibenzo(a,h) anthracene		12	33	15	7	Yes
Dibenzofuran		15	58	10	9	Yes
Fluoranthene		160	1,200	14	9	Yes
Fluorene		23	79	2	5	Yes
Indeno(1,2,3-cd) pyrene		34	88	10	7	Yes
Phenanthrene		100	480	6	9	Yes
Pyrene		1,000	1,400	0	3	Yes
Total HPAH		960	5,300	11	13	Yes
Total LPAH		370	780	5	2	Yes
Phthalates						
Bis(2-ethylhexyl) phthalate	mg/kg OC	47	78	4	5	Yes
Butyl benzyl phthalate		4.9	64	16	0	Yes
Di-n-butyl phthalate		220	1,700	0	1	Yes
Other SVOCs						
1,4-Dichlorobenzene	mg/kg OC	3.1	9	21	9	Yes
2,4-Dimethylphenol	µg/kg dw	29	29	0	9	Yes

Table 3-1
Summary of COCs and Selection of Risk Driver COCs for Benthic Invertebrates Based on Surface Sediment Exposure

COC	SMS Criteria			No. of Detected Concentrations in Surface Sediments		Risk Driver?
	Unit	SQS	CSL	> SQS, ≤ CSL	> CSL	
n-Nitrosodiphenylamine	mg/kg OC	11	11	0	3	Yes
Phenol	µg/kg dw	420	1,200	5	0	Yes
PCBs						
Total PCBs	mg/kg OC	12	65	137	23	Yes
Pesticides						
Total DDTs	µg/kg dw	6.9[a]	69[a]	2	0	No

Notes:
This table is derived from Table A.6-1 of the ERA (Windward 2012a), updated with 8 surface sediment samples from Slip 36 (see Section 2.10).
a. No SQS or CSL values are available for total DDTs. Thus, the comparison is with the DMMP SL and ML.

µg/kg – micrograms per kilogram
COC – contaminant of concern
CSL – cleanup screening level
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredged Material Management Program
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
ML – maximum level
OC – organic carbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RI – remedial investigation
SL – screening level
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SVOC – semivolatile organic compound

not the CSL representing a potential for minor adverse effects in these areas. The remaining 39% of the EW (61 acres) is considered unlikely to have adverse effects on the benthic invertebrate community.[22]

VOCs in sediment porewater were considered unlikely to pose a risk to the benthic invertebrate community, except for naphthalene, which had a concentration that exceeded toxicity data representing the lowest observed effect concentration (LOEC) at one location. Naphthalene was selected as a COC for the benthic invertebrate community based on porewater exposure.

[22] As noted in Section 2.10.1, these values differ slightly from those presented in the EW SRI (Windward and Anchor QEA 2014) due to inclusion of Slip 36 data collected in 2014. Areas are based on 157 acres of sediment in the study area.

The potential for adverse effects from exposure to TBT was identified for benthic invertebrates in 2 of the 12 benthic invertebrate tissue sampling areas because the LOAEL TRV for TBT was exceeded in samples collected from those areas. Mercury and PCBs were considered unlikely to pose a risk to the benthic invertebrate community based on concentrations in tissue. TBT was selected as a COC based on concentrations in benthic invertebrate tissue.

Finally, there is uncertainty in the risk posed to the benthic invertebrate community from exposure to TBT in surface water because the TBT concentration exceeded the recommended federal chronic WQC in one sample, but was undetected in the remaining 30 samples with reporting limits (RLs) slightly exceeding the WQC.[23] Therefore, TBT was also selected as a COC for benthic invertebrates based on the surface water evaluation.

3.1.2 Crabs, Fish, and Wildlife Species

COCs were identified for crabs, fish, and wildlife species if LOAEL-based HQs were greater than or equal to 1. In addition, COCs were defined for crabs and fish if exposure concentrations in surface water exceeded chronic WQC or TRV.

Cadmium, copper, and zinc were identified as COCs for crabs based on the tissue residues evaluation, indicating the potential for adverse effects. The tissue residue evaluation for fish resulted in the identification of TBT as a COC for brown rockfish and total PCBs as COCs for English sole and brown rockfish.

Cadmium was identified as a COC for juvenile Chinook salmon, English sole, and brown rockfish based on the dietary exposure evaluation. In addition, the potential for adverse effects was identified for English sole from exposure to copper and vanadium in the diet.

[23] It should be noted that all of the RL values were above the chronic marine ambient WQC value of 0.0074 micrograms per liter (μg/L). The surface water samples were analyzed by the most sensitive, commercially available analytical method. The TBT method detection limit (MDL) values were below the chronic marine ambient WQC, and the laboratory was required to report values between the MDL and the RL as estimated. No estimated values were reported.

No COCs were identified for fish or crabs based on the surface water evaluation, or for wildlife based on the dietary exposure evaluation.

3.1.3 Risk Driver COCs for Ecological Receptors

A subset of the COCs was identified as risk drivers for ecological receptors based on the risk estimates, uncertainties discussed in the ERA (Windward 2012a), and Puget Sound Ambient Monitoring Program (PSAMP) rural Puget Sound concentrations in accordance with EPA (1992, 1997a, 1997b, 1998) guidance and consistent with the LDW ERA (Windward 2007a). The rationale for identifying these risk driver COCs can be found in Section 7 of the baseline ERA (Windward 2012a) and is summarized in Tables 3-1 and 3-2. Risk driver COCs for ecological receptors of concern were selected by considering: 1) the uncertainty in risk estimates based on quantity and quality of exposure and effects data, 2) magnitude of exposure concentrations compared to TRVs, and 3) comparison of concentrations in EW sediment with PSAMP rural Puget Sound background concentrations in sediment.

Table 3-2
Summary of COCs and Selection of Risk Drivers for Ecological Receptors[a]

Receptor of Concern – Type of Evaluation	COC[b]	LOAEL-based HQ	Risk Driver?	Rationale for Selection or Exclusion as Risk Driver
Benthic invertebrate community – tissue	TBT	3.3	Yes	LOAEL-based HQs greater than 1.0 in two areas of the EW; low uncertainty in exposure data
Benthic invertebrate community – surface water	TBT	1.4	No	High uncertainty in surface water dataset; only one detected value; low LOAEL-based HQ
Benthic invertebrate community – porewater	Naphthalene	6	No	High uncertainty in effects data; only one porewater sample had a concentration exceeding the low-effect HQ; naphthalene did not exceed the SMS in any sediment samples
Crab – tissue	Cadmium	1.4	No	Three COCs identified for crab were not selected as risk drivers because
	Copper	1.1	No	

Table 3-2
Summary of COCs and Selection of Risk Drivers for Ecological Receptors[a]

Receptor of Concern – Type of Evaluation	COC[b]	LOAEL-based HQ	Risk Driver?	Rationale for Selection or Exclusion as Risk Driver
	Zinc	1.5	No	site sediment concentrations were similar to PSAMP rural Puget Sound concentrations (cadmium and copper) and because of uncertainties in the effects data for all three COCs, including the lack of toxicity data for crabs
English sole – tissue	Total PCBs	1.6 – 7.9[c]	Yes	HQ based on higher LOAEL TRV, which was associated with significant effects, was >1.0; low uncertainty in exposure data
Brown rockfish – tissue	Total PCBs	2.3 – 12[c]	Yes	
	TBT	1.4	No	High uncertainty in toxicity dataset; exposure concentration representing the population of rockfish did not exceed LOAEL; low LOAEL-based HQ
Juvenile Chinook salmon – diet	Cadmium	1.0	No	Three dietary COCs for fish were not selected as risk drivers because the site sediment concentrations were similar to PSAMP rural Puget Sound concentrations and because of uncertainties in exposure or effects data
English sole – diet	Cadmium	2.4	No	
	Copper	1.1	No	
	Vanadium	1.9	No	
Brown rockfish – diet	Cadmium	2.5	No	

Notes:
a. No COCs were identified for birds and mammals. Benthic risk drivers are presented separately in the text below.
b. A contaminant was identified as a COC if the LOAEL-based HQ was greater than or equal to 1.0; however, for juvenile Chinook salmon, NOAEL-based HQs were used because it is a listed species.
c. HQs were calculated from a range of effects concentrations because of uncertainty in the TRVs.

COC – contaminant of concern
HQ – hazard quotient
LOAEL – lowest-observed-adverse-effect level
NOAEL – no-observed-adverse-effect level
PCB – polychlorinated biphenyl
PSAMP – Puget Sound Ambient Monitoring Program
RI – remedial investigation
TBT – tributyltin

In the baseline ERA (Windward 2012a), 30 contaminants were selected as COCs for benthic invertebrates. Of these, 29 contaminants were selected as risk drivers for benthic invertebrates because they had concentrations greater than the SQS in at least one sediment sample (Table 3-1) and SMS is a key regulation governing sediment remediation in the State of Washington. The remaining COC, total DDTs, was not selected as a risk driver because of the low detection frequency, known analytical uncertainties from PCB interference, and uncertainties in the effects data. TBT was identified as a risk driver for the benthic invertebrate community for the tissue evaluation because of two LOAEL-based HQs greater than 1 and low uncertainty in the exposure data. Total PCBs was selected as a risk driver for English sole and brown rockfish because PCBs in tissue residues exceeded the higher LOAEL TRV that was associated with significant effects and uncertainties are low in the exposure data (Table 3-2). Non-risk driver COCs are evaluated to assess the potential for risk reduction following remedial actions; the results of this analysis are presented in Section 9 of this FS.

3.2 Baseline Human Health Risk Assessment

The baseline HHRA (Windward 2012b) estimated risks to people from exposure to contaminants in EW seafood, sediments, and water. The exposures were assumed to occur through consumption of resident seafood harvested from the EW; direct contact with sediments during netfishing, clamming, or habitat restoration (which include the pathways of dermal contact and incidental ingestion of sediment); and direct contact with surface water while swimming. To the extent possible, this HHRA is consistent with the approach and methods that were approved by EPA for use in the HHRA for the LDW (Windward 2007a).

Using EPA guidance, a risk-based screening was first performed to identify the COPCs to be evaluated. This screening process was based on an exceedance of the screening criteria (i.e., the risk-based concentration) by either the maximum detected concentrations or analytical RLs (for samples with non-detected concentrations). The COPCs for each exposure scenario were then evaluated to estimate risks and determine COCs.

Risks estimated for the seafood consumption and direct exposure scenarios evaluated in the HHRA (Windward 2012b) are discussed in the following subsections. In January 2017, subsequent to the HHRA, the benzo(a)pyrene cancer slope factor (which is used to calculate the excess cancer risk for cPAHs) was updated in EPA's Integrated Risk Information System (IRIS) database. This section includes updated lifetime excess cancer risk estimates for cPAHs based on the updated slope factor as compared with those presented in HHRA, and includes updated the COC and risk-driver designations for cPAHs. An addendum to the HHRA describes the effects of the cancer slope factor change for the assessment of cPAHs in the HHRA (Windward 2019).

3.2.1 Risks Associated with the Seafood Consumption Pathway

No seafood consumption surveys specific to the EW were available for use in the HHRA (Windward 2012b). Therefore, the EW HHRA used seafood consumption rates developed by EPA based on data collected from other areas of Puget Sound for tribal consumers and from an EPA seafood consumption study for Asian and Pacific Islanders (API) in the King County area. The seafood consumption rates used in the EW HHRA are the same as those used to evaluate risks in the LDW HHRA (Windward 2007a, 2009).

Seafood consumption scenarios with different levels of exposure were evaluated in the baseline HHRA to provide a broad range of risk estimates. Reasonable maximum exposure (RME) estimates, which will be used for making decisions about the need for remediation at the site, included the following seafood consumption rates:

- Tulalip tribal consumption rates for adults and children from EPA's tribal framework document (EPA 2007)
- Seafood consumption rates for API adults, modified by EPA based on the results of a survey of API consumers (EPA 1999b) to reflect rates by individuals that harvest seafood only within King County

RME scenarios are the highest exposure that is reasonably expected to occur at a site. The RME, by definition, likely overestimates exposure for many individuals. Additionally, it should be noted that the tribal consumption rates are likely overestimates of current consumption of resident seafood specifically from the EW. However, such rates may be achieved in the EW at some future time.

Other seafood consumption scenarios were also evaluated in the baseline HHRA (Windward 2012b). These other scenarios included consumption rates estimated using: 1) Suquamish tribal consumption rates from EPA's tribal framework document (EPA 2007); 2) "average exposure" scenarios using central tendency (CT) consumption rate estimates; and 3) a "unit risk" scenario based on an assumed one seafood meal per month. Estimates for the unit risk scenario are useful for risk communication because individuals can determine what their risk might be for various seafood consumption practices. For the EW, given the limited quantity of current or potential shellfish habitat (particularly high-quality habitat), the Tulalip Tribes' rate was selected, as approved by EPA (Windward 2010e), to characterize the RME seafood consumption risks in the EW. Inasmuch as the EW is within the U&A fishing area of the Suquamish Tribe, and the Suquamish Tribe requested that their seafood consumption data be used to characterize risk, the EW HHRA also evaluated risk using Suquamish Tribe consumption rates. Although, EPA's tribal framework supports consistency in internal EPA policy regarding tribal seafood consumption risk assessment, the recommendations of the framework (EPA 2007) do not replace or supersede the need for consultation between EPA and the tribes to develop site-specific risk assessments. Discussions between EPA and the Suquamish Tribe did not result in tribal concurrence regarding the use of the Tulalip tribal consumption rates as the RME scenario for the EW HHRA. The Suquamish Tribe requested that the tribal RME scenario be represented as a range of exposures based on the Tulalip and Suquamish consumption rates. Rather, the use of the Tulalip rates represents an EPA policy decision. However, the Muckleshoot and Suquamish Tribes recognize that sediment cleanup levels for bioaccumulative risk driver contaminants based on seafood consumption risks will likely be below background, regardless of whether Tulalip or Suquamish consumption rates are used to develop cleanup levels. For this reason, the tribes have not pursued their disagreement with EPA more vigorously regarding the selection of the Tulalip Tribes' rate to characterize RME seafood consumption risks for the EW. The tribes regard the EW seafood consumption rate decision to be site-specific and do not regard it as being precedent-setting.

It is noted that there is considerable uncertainty about the applicability of seafood consumption rates in the baseline HHRA (Windward 2012b), particularly for clams, given the limited quality of existing or potential future shellfish habitat (particularly high-quality habitat) in the EW. Nonetheless, their use in the HHRA reflects health-protective estimates of risk.

Contaminant concentrations in the tissues of a variety of different resident seafood species (English sole, perch, rockfish, crabs, clams, geoduck, and mussels) were used to represent a typical consumer's diet (i.e., a market basket approach was used to evaluate risks associated with seafood consumption). COCs were then determined by estimating cancer and non-cancer effects for the RME scenarios. Contaminants with an estimated excess cancer risk greater than 1 in 1,000,000 (1×10^{-6}) or a non-cancer HQ greater than 1 were selected as

COCs for the seafood consumption exposure pathway. Eleven COPCs were identified as COCs for the seafood consumption exposure pathway (Table 3-3).[24]

Table 3-3

Summary of COCs for the HHRA

COCs Identified for One or More RME Scenarios	Seafood Consumption Scenarios			Direct Sediment Exposure Scenarios	
	Adult Tribal RME (Tulalip Data)	Child Tribal RME (Tulalip Data)	Adult API RME	Netfishing RME	Tribal Clamming RME
Arsenic	X	X	X	X	X
Cadmium		X			
cPAH (TEQ)	X	X	X	O[a]	X
Pentachlorophenol	X				
Total PCBs	X	X	X		X
PCB (TEQ)	X	X	X		
alpha-BHC	X				
Dieldrin	X		X		
Total chlordane	X				
Heptachlor epoxide	X				
Mirex	X				
Dioxins/furans (TEQ)	X	X	X		
Total TEQ[b]					X

Notes:

a. cPAH TEQ was identified as a COC for netfishing in the HHRA. Subsequent to the HHRA, the cancer slope factor was updated in EPA's Integrated Risk Information System (IRIS) database for benzo[*a*]pyrene. This reduced the cPAH TEQ risks calculated in this FS as compared with the risks calculated in the HHRA. The updated cPAH TEQ netfishing risks for the RME scenario are below 1×10^{-6}, which results in the elimination of cPAH TEQ from the list of COCs for the netfishing RME scenario.The updated risks for cPAH TEQ for all scenarios are documented in the HHRA addendum (Windward 2019) and this section of the FS. Further, because cPAH TEQ is not a COC for netfishing based on updated cancer slope factor, it is also no longer a risk driver for netfishing and therefore is not discussed for this scenario in later sections of the FS (e.g., see Table 3-14).

[24] As presented in Table 3-3, both total PCBs (i.e., the sum of detected Aroclors) and dioxin-like PCB toxic equivalents (TEQs) were identified in the HHRA as COCs. Because these two COCs represent different methods of evaluating the same contaminant, they are counted as one COC in the count presented here. The risk from total PCBs calculated as a sum of detected Aroclors was approximately equal to or up to two times higher than the risk calculated from the PCB TEQ (EW SRI Section 6.3.2; Windward and Anchor QEA 2014). This is because dioxin-like PCBs included in the PCB TEQs are also accounted for as part of the total PCB sum, and thus contribute to cancer risk estimates calculated for total PCBs. Therefore, only total PCBs were retained in the FS for the alternatives analysis.

b. Total TEQ is equal to the sum of PCB TEQ and dioxin/furan TEQ. When excess cancer risks for either PCB TEQ or dioxin/furan TEQ were not independently greater than 1×10^{-6}, the sum of these two chemicals (total TEQ) was identified as a COC if it was greater than this threshold.

API – Asian and Pacific Islander
BHC – benzene hexachloride
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
HHRA – human health risk assessment
O – Retained as a COC in the HHRA, but dropped as a COC in the FS (see table note a)
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent
X – Retained as COC

The total excess cancer risk for all carcinogenic contaminants for the various RME seafood consumption scenarios ranged from 5 in 10,000 (5×10^{-4}) to 1 in 1,000 (1×10^{-3}),[25] with the primary contributors to risk being total PCBs, arsenic, cPAHs, and dioxins/furans (Table 3-4a).[26] In addition, evaluation of non-cancer HQs indicates the potential for adverse effects other than cancer associated with seafood consumption, particularly from total PCBs (Table 3-4b).

To provide additional information regarding the total excess cancer risks for the RME seafood consumption scenarios, Table 3-5 presents a summary of the excess cancer risks for COCs and includes the percentages of the total risks attributable to different COCs and seafood consumption categories (i.e., fish, crabs, clams, geoduck, and mussels). The main contributors to the total excess cancer risk for the RME seafood consumption scenarios were total PCBs (73% to 76% of the total risk), arsenic (13% to 14% of the total risk), cPAHs (1% to 5% of the total risk), and dioxins/furans (7% of the total risk). In addition, Table 3-5 shows that the majority of the arsenic and cPAH risks (73% to 90%) are attributable to clams, while the total PCB and dioxin/furan risk is attributable to several different seafood consumption categories and is more variable across scenarios. For total PCBs, the risk is primarily attributable to benthic fish fillet (16% to 41%), rockfish (9% to 59%), perch (3% to 26%), crab edible meat (3% to 10%), and whole body crab (7% to 9%). For dioxins/furans, the risk is primarily attributable to clams (25% to 31%), crab edible meat (8% to 22%), whole body crab (18%), and rockfish (5% to 35%).

[25] As noted in the footnote above, the total risk estimate includes risks from total PCBs but excludes risks from PCBs from a TEQ perspective to avoid double counting dioxin-like PCB risks posed by coplanar PCB congeners that are already accounted for in the slope factor for PCBs.

[26] Risk associated with many chlorinated pesticides was based largely on non-detect results.

3.2.2 Risks Associated with Direct Sediment Contact

The direct sediment exposure scenarios evaluated in the EW HHRA (Windward 2012b) included two netfishing scenarios (RME and CT), a habitat restoration worker scenario, and three clamming scenarios: 1) tribal RME (120 days per year); 2) high-end exposure included at the request of the Suquamish Tribe (183 days per year); and 3) 7 days per year.[27] As in the LDW HHRA (Windward 2007a), exposure frequency and duration assumptions for the evaluation of direct sediment exposure under the commercial netfishing scenario were based on site use information collected from the Muckleshoot Indian Tribe, which conducts commercial netfishing for adult salmon in the Green/Duwamish River, including the EW. No site-specific information was available to estimate exposure for the clamming and habitat restoration scenarios and, thus, exposure parameters were (when possible) consistent with the LDW and/or were based on default EPA values and best professional judgment. Netfishing can occur throughout the EW (i.e., in intertidal and subtidal areas), while clamming and habitat restoration activities would occur in specific areas of the EW (i.e., in specific intertidal areas), which are shown in Figure 3-1. Intertidal sediment areas (i.e., not riprap) were identified as potential clamming areas and were surveyed for the EW SRI as described in Sections 2.9.3 and 2.9.4 herein.

Excess cancer risks for the direct sediment exposure scenarios were much lower than those for the seafood consumption scenarios (Table 3-6). Excess cancer risks for all scenarios were less than the upper end of EPA's risk range (1 in 10,000 [1×10^{-4}]), with total excess cancer risks equal to 5 in 1,000,000 (5×10^{-6}) for the netfishing RME scenario and 2 in 100,000 (2×10^{-5}) for the tribal clamming RME scenario. Cancer risks were highest for arsenic, which accounts for 63% to 67% of the total excess cancer risk for the RME scenarios. cPAHs, PCBs, and dioxin/furan TEQ were lesser contributors. No COPCs had non-cancer HQs greater than 1 for any of the direct sediment exposure scenarios. In addition, the total hazard index (HI) for each exposure scenario did not exceed 1. Therefore, non-cancer hazard was not the basis for selection of any direct contact COC.

[27] The EW HHRA does not include an evaluation of the child beach play scenario because of the lack of suitable exposure areas.

Table 3-4a
Estimated Excess Cancer Risks for the HHRA Seafood Consumption Scenarios

COPC[a]	Estimated Excess Cancer Risk											
	Adult Tribal RME (Tulalip Data)	Adult Tribal CT (Tulalip Data)	Child Tribal RME (Tulalip Data)	Child Tribal CT (Tulalip Data)	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Adult One Meal per Month: Benthic Fish	Adult One Meal per Month: Clam	Adult One Meal per Month: Crab	Adult One Meal per Month: Pelagic Fish, Rockfish	Adult One Meal per Month: Pelagic Fish, Perch
Arsenic[b]	2×10^{-4}	1×10^{-5}	4×10^{-5}	4×10^{-6}	2×10^{-3}	8×10^{-5}	2×10^{-6}	3×10^{-7}[c]	1×10^{-5}	2×10^{-6}	7×10^{-7}	2×10^{-6}
cPAHs (TEQ)[d]	1×10^{-5}	6×10^{-7}	1×10^{-5}	1×10^{-6}	1×10^{-4}	7×10^{-6}	1×10^{-7}	2×10^{-8}	1×10^{-6}	5×10^{-8}	1×10^{-8}	7×10^{-8}
1,4-Dichlorobenzene	1×10^{-6}[e]	7×10^{-8}[e]	2×10^{-7}[e]	3×10^{-8}[e]	7×10^{-6}[e]	4×10^{-7}[e]	8×10^{-9}[e]	4×10^{-8}[c]	4×10^{-8}[c]	4×10^{-8}[c]	4×10^{-8}[c]	2×10^{-7}[c]
Pentachlorophenol	2×10^{-6}[e]	4×10^{-8}[e]	4×10^{-7}[e]	2×10^{-8}[e]	2×10^{-5}[e]	3×10^{-7}	4×10^{-9}	1×10^{-8}[c]	4×10^{-8}	1×10^{-8}[c]	1×10^{-8}[c]	3×10^{-8}[c]
Total PCBs	1×10^{-3}	5×10^{-5}	2×10^{-4}	2×10^{-5}	9×10^{-3}	4×10^{-4}	7×10^{-6}	2×10^{-4}	6×10^{-6}	1×10^{-5}	4×10^{-4}	1×10^{-4}
PCBs (TEQ)[f]	7×10^{-4}	4×10^{-5}	1×10^{-4}	2×10^{-5}	6×10^{-3}	3×10^{-4}	8×10^{-6}	1×10^{-4}	5×10^{-6}	1×10^{-5}	3×10^{-4}	9×10^{-5}
Total DDTs	1×10^{-6}	9×10^{-8}	2×10^{-7}	4×10^{-8}	1×10^{-5}	6×10^{-7}	1×10^{-8}	2×10^{-7}	2×10^{-8}	2×10^{-8}[c]	5×10^{-7}	2×10^{-7}
alpha-BHC	4×10^{-6}[e]	2×10^{-7}[e]	7×10^{-7}[e]	1×10^{-7}[e]	2×10^{-5}[e]	9×10^{-7}[e]	3×10^{-8}[e]	1×10^{-7}[c]	1×10^{-7}[c]	1×10^{-7}[c]	2×10^{-7}	1×10^{-7}[c]
beta-BHC	1×10^{-6}[e]	7×10^{-8}[e]	2×10^{-7}[e]	3×10^{-8}[e]	7×10^{-6}[e]	3×10^{-7}[e]	8×10^{-9}[e]	4×10^{-8}[c]	4×10^{-8}[c]	3×10^{-8}[c]	4×10^{-8}[c]	3×10^{-8}[c]
Dieldrin	8×10^{-6}[e]	5×10^{-7}[e]	1×10^{-6}[e]	2×10^{-7}[e]	5×10^{-5}[e]	2×10^{-6}[e]	7×10^{-8}[e]	2×10^{-7}	3×10^{-7}[c]	3×10^{-7}[c]	4×10^{-7}	5×10^{-7}
Total chlordane	2×10^{-6}	9×10^{-8}	3×10^{-7}	4×10^{-8}	1×10^{-5}	7×10^{-7}	1×10^{-8}	4×10^{-8}	8×10^{-8}	2×10^{-8}[c]	1×10^{-7}	5×10^{-8}
Heptachlor	1×10^{-6}[e]	7×10^{-8}[e]	2×10^{-7}[e]	3×10^{-8}[e]	7×10^{-6}[e]	3×10^{-7}[e]	1×10^{-8}[e]	4×10^{-8}[c]	4×10^{-8}[c]	4×10^{-8}[c]	5×10^{-8}[c]	4×10^{-8}[c]
Heptachlor epoxide	2×10^{-6}[e]	2×10^{-7}[e]	4×10^{-7}[e]	7×10^{-8}[e]	1×10^{-5}[e]	7×10^{-7}[e]	2×10^{-8}[e]	9×10^{-8}[c]	9×10^{-8}[c]	9×10^{-8}[c]	1×10^{-7}	9×10^{-8}[c]
Mirex	4×10^{-6}[e]	3×10^{-7}[e]	8×10^{-7}[e]	1×10^{-7}[e]	3×10^{-5}[e]	1×10^{-6}[e]	4×10^{-8}[e]	2×10^{-7}[c]	2×10^{-7}[c]	2×10^{-7}[c]	4×10^{-7}	2×10^{-7}[c]
Dioxin/furan (TEQ)[f]	1×10^{-4}	6×10^{-6}	2×10^{-5}	3×10^{-6}	7×10^{-4}	4×10^{-5}	1×10^{-6}	5×10^{-6}	3×10^{-6}	3×10^{-6}	2×10^{-5}	9×10^{-6}
Total TEQ (dioxins/furans and coplanar PCBs)	8×10^{-4}	5×10^{-5}	1×10^{-4}	2×10^{-5}	7×10^{-3}	3×10^{-4}	9×10^{-6}	1×10^{-4}	8×10^{-6}	1×10^{-5}	3×10^{-4}	1×10^{-4}
Total excess cancer risk (excluding PCB TEQ)[g]	**1×10^{-3}**	**7×10^{-5}**	**3×10^{-4}**	**3×10^{-5}**	**1×10^{-2}**	**5×10^{-4}**	**1×10^{-5}**	**2×10^{-4}**	**2×10^{-5}**	**2×10^{-5}**	**4×10^{-4}**	**1×10^{-4}**
Total excess cancer risk (excluding total PCBs)[h]	**1×10^{-3}**	**6×10^{-5}**	**2×10^{-4}**	**3×10^{-5}**	**9×10^{-3}**	**4×10^{-4}**	**1×10^{-5}**	**1×10^{-4}**	**2×10^{-5}**	**2×10^{-5}**	**3×10^{-4}**	**1×10^{-4}**

Notes:

Shaded cells indicate excess cancer risks greater than 1×10^{-6}.

a. Only those COPCs with an excess cancer risk greater than 1×10^{-6} for one or more scenarios are included in this table.
b. Arsenic exposure point concentrations and risk estimates are based on inorganic arsenic.
c. There were no detected values of this COPC for this seafood category. Risk estimate was based on one-half the maximum RL.
d. The higher contribution of cPAHs to overall children's cancer risks is because cPAHs have a mutagenic mode of action and pose greater risks to children than adults. EPA risk assessment procedures account for the greater cancer risks mutagens pose to children.
e. Greater than 50% of the risk associated with this COPC was derived from seafood categories with no detected values.
f. No mussel data were available for this COPC. When the CDI and risk values were calculated, the portion of seafood consumption that had been assigned to mussels was divided proportionally among the remaining consumption categories.
g. Total risk values include the risks associated with all COPCs. Total PCBs is included in the total, and total PCBs TEQ is not included to avoid double-counting risks due to PCBs.
h. Total risk values include the risks associated with all COPCs. Total PCBs TEQ is included in the total, and total PCBs not included to avoid double-counting risks due to PCBs.

API – Asian and Pacific Islander
BHC – benzene hexachloride
CDI – chronic daily intake
COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CT – central tendency
DDT – dichlorodiphenyltrichloroethane
EPA – U.S. Environmental Protection Agency
FS – Feasibility Study
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RL – reporting limit
RME – reasonable maximum exposure
TEQ – toxic equivalent

Table 3-4b
Estimated Non-cancer Hazards for the HHRA Seafood Consumption Scenarios

COPC[a]	Estimated Non-Cancer Hazard											
	Adult Tribal RME (Tulalip Data)	Adult Tribal CT (Tulalip Data)	Child Tribal RME (Tulalip Data)	Child Tribal CT (Tulalip Data)	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Adult One Meal per Month				
								Benthic Fish	Clam	Crab	Pelagic Fish, Rockfish	Pelagic Fish, Perch
Arsenic[b]	0.4	0.05	0.9	0.1	4	0.4	0.03	0.002	0.08	0.01	0.004	0.009
Cadmium	0.7	0.08	2	0.2	2	0.4	0.03	0.01	0.01	0.09	0.004	0.004
Cobalt	0.6	0.07	1	0.2	4	0.5	0.04	0.01	0.07	0.05	0.02	0.02
Mercury	0.6	0.07	1	0.2	3	0.4	0.04	0.05	0.02	0.09	0.2	0.04
TBT as ion	0.3	0.03	0.7	0.07	4	0.4	0.03	0.007	0.05	0.003	0.2	0.04
Total PCBs[c]	27	3	58	6	214	24	1	13	0.4	0.8	21	8
Total PCBs[d]	8	0.8	17	2	61	7	0.4	4	0.1	0.2	6	2
PCB TEQ[e]	7	0.9	14	2	58	7	0.6	2	0.1	0.3	6	2
Dioxin/furan TEQ[e]	1	0.1	2	0.3	7	0.9	0.07	0.1	0.06	0.07	0.4	0.2
Total TEQ[e]	**8**	**1**	**16**	**2**	**65**	**8**	**0.7**	**2**	**0.2**	**0.4**	**6**	**2**
HIs by Endpoint:												
Hematological endpoint[f]	**0.3**	**0.05**	**0.8**	**0.1**	**2**	**0.2**	**0.02**	**0.01**	**0.02**	**0.04**	**0.03**	**0.02**
Immunological endpoint[g]	**27**	**3**	**59**	**6**	**218**	**24**	**1**	**13**	**0.5**	**0.8**	**21**	**8**
Kidney endpoint[h]	**0.8**	**0.1**	**2**	**0.2**	**3**	**0.5**	**0.04**	**0.02**	**0.02**	**0.1**	**0.01**	**0.01**
Liver endpoint[i]	**0.06**	**0.008**	**0.1**	**0.02**	**0.3**	**0.04**	**0.003**	**0.007**	**0.006**	**0.004**	**0.01**	**0.008**
Neurological endpoint[j]	**28**	**3**	**59**	**6**	**218**	**25**	**1**	**13**	**0.4**	**0.9**	**21**	**8**
Endocrine endpoint[k]	**0.6**	**0.08**	**1**	**0.2**	**4**	**0.5**	**0.04**	**0.01**	**0.08**	**0.05**	**0.02**	**0.02**
Integumentary endpoint[l]	**28**	**3**	**59**	**6**	**219**	**25**	**1**	**13**	**0.5**	**0.8**	**21**	**8**
Digestive system endpoint[m]	**0.5**	**0.06**	**1**	**0.1**	**2**	**0.3**	**0.03**	**0.005**	**0.04**	**0.04**	**0.02**	**0.02**
Developmental endpoint[n]	**10**	**1**	**16**	**2**	**65**	**8**	**0.7**	**4**	**0.2**	**0.5**	**7**	**2**

Notes:

Shaded cells indicate non-cancer HQs greater than 1.

a. Only those COPCs with HQs greater than 1 for one or more scenario are included in this table.
b. Arsenic exposure point concentrations and risk estimates are based on inorganic arsenic.
c. HQ used for the calculation of the immunological, integumentary, and neurological endpoint HIs (Table B.4-1 of the HHRA, Windward 2012b).
d. HQ used for the calculation of the developmental endpoint HI (Table B.4-1 of the HHRA; Windward 2012b).
e. HQs for PCB and dioxin/furan TEQs were not presented in the EW HHRA because no RfD was available to calculate these values. The recently released RfD for 2,3,7,8-TCDD has since been used to calculate the HQs presented in this table. Additional information regarding these new HQs are presented in Attachment 7 to the HHRA (Appendix B of the SRI; Windward and Anchor QEA 2014).
f. Hematological endpoint includes the following chemicals: antimony, selenium, and zinc.
g. Immunological endpoint includes the following chemicals: dibutyltin, total PCBs, and TBT.
h. Kidney endpoint includes the following chemicals: cadmium, molybdenum, and pentachlorophenol.
i. Liver endpoint includes the following chemicals: 1,4-dichlorobenzene, alpha-BHC, total chlordane, total DDTs, dieldrin, heptachlor, heptachlor epoxide, mirex, and pentachlorophenol.
j. Neurological endpoint includes the following chemicals: mercury, total PCBs, and selenium. Neurological effects associated with exposure to lead are discussed in the HHRA, Section B.5.4 (Windward 2012b).
k. Endocrine endpoint includes the following chemicals: antimony and cobalt.
l. Integumentary endpoint includes the following chemicals: arsenic, total PCBs, selenium, and vanadium.
m. Digestive system endpoint includes the following chemicals: chromium and copper.
n. Developmental endpoint includes the following chemicals: mercury, PCBs (the higher of either the total PCB HQ based on the developmental RfD or the PCB TEQ HQ), and dioxin/furan TEQ.

API – Asian and Pacific Islander
BHC – benzene hexachloride
COPC – contaminant of potential concern
CT – central tendency
DDT – dichlorodiphenyltrichloroethane
HHRA – human health risk assessment
HI – hazard index
HQ – hazard quotient
PCB – polychlorinated biphenyl
RfD – reference dose
RME – reasonable maximum exposure
SRI – Supplemental Remedial Investigation
TBT – tributyltin
TEQ – toxic equivalent

Table 3-5
Summary of Estimated Excess Cancer Risks for the RME Seafood Consumption Scenarios

COC	Adult Tribal RME (Tulalip Data)		Child Tribal RME (Tulalip Data)		Adult API RME	
	Excess Cancer Risk (% of Total[a])	Percent of Risk by Seafood Consumption Category[b]	Excess Cancer Risk (% of Total[a])	Percent of Risk by Seafood Consumption Category[b]	Excess Cancer Risk (% of Total[a])	Percent of Risk by Seafood Consumption Category[b]
Arsenic (inorganic)	2×10^{-4} (14%)	82% clams; 8.9% crab EM	4×10^{-5} (13%)	82% clams; 8.9% crab EM	8×10^{-5} (14%)	87% clams; 6.0% mussels
cPAHs (TEQ)	1×10^{-5} (1%)	90% clams	1×10^{-5} (5%)	90% clams	7×10^{-6} (1%)	73% clams; 25% mussels
Total PCBs	1×10^{-3} (76%)	41% benthic fillet; 26% perch; 9.5% crab EM; 9.1% rockfish; 8.5% crab WB; 6.1% clams	2×10^{-4} (73%)	41% benthic fillet; 26% perch; 9.5% crab EM; 9.1% rockfish; 8.5% crab WB; 6.1% clams	4×10^{-4} (76%)	59% rockfish; 16% benthic fillet; 7.3% crab WB; 6.7% clams; 5.5% benthic WB
PCBs (TEQ)	7×10^{-4}	30% benthic fillet; 27% perch; 13% crab WB; 12% crab EM; 11% rockfish; 7.7% clams	1×10^{-4}	30% benthic fillet; 27% perch; 13% crab WB; 12% crab EM; 11% rockfish; 7.7% clams	3×10^{-4}	62% rockfish; 11% benthic fillet; 9.7% crab WB; 7.5% clams; 4.8% benthic WB
Dioxin/furan (TEQ)	1×10^{-4} (7%)	25% clams; 22% crab EM; 18% crab WB; 17% perch; 10% benthic fillet	2×10^{-5} (7%)	25% clams; 22% crab EM; 18% crab WB; 17% perch; 10% benthic fillet	4×10^{-5} (7%)	35% rockfish; 31% clams; 18% crab WB; 7.9% crab EM
Other COCs[c]	3×10^{-5} (2%)	nc	4×10^{-6} (2%)	nc	7×10^{-6} (2%)	nc
Total excess cancer risk and main contributors to the total risk[d]	**1×10^{-3}**	**31% – PCBs in benthic fillet 19% – PCBs in perch 11% – arsenic in clams 7.2% – PCBs in crab EM 6.9% – PCBs in rockfish 6.4% – PCBs in crab WB 18% – other**	**3×10^{-4}**	**30% – PCBs in benthic fillet 18% – PCBs in perch 11% – arsenic in clams 6.9% – PCBs in crab EM 6.6% – PCBs in rockfish 6.1% – PCBs in crab WB 22% – other**	**5×10^{-4}**	**44% – PCBs in rockfish 12% – arsenic in clams 12% – PCBs in benthic fillet 5.6% – PCBs in crab WB 5.1% – PCBs in clams 21% – other**

Notes:

a. Total excess cancer risk includes the risks associated with all COPCs, including total PCBs but excluding PCB TEQ.
b. Seafood consumption categories contributing greater than 5% of the risk for each COC are listed in this table.
c. Together, all other COCs contributed less than 2% to the total excess cancer risk.
d. Seafood consumption category-COC combinations contributing greater than 5% of the total risk are listed separately. All other combinations are included in the "other" category. Total PCBs is included in the total, and total PCBs TEQ is not included to avoid double-counting risks due to PCBs.

API – Asian and Pacific Islander
cPAH – carcinogenic polycyclic aromatic hydrocarbon
COC – contaminant of concern
COPC – contaminant of potential concern
EM – edible meat
HHRA – human health risk assessment
nc – not calculated
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent
WB – whole body

Table 3-6

Estimated Excess Cancer Risks for the HHRA Direct Sediment Exposure Scenarios

COPC	Estimated Excess Cancer Risk					
	Netfishing		Habitat Restoration Worker	Clamming		
	RME	CT		Tribal RME	Tribal – 183 Days per Year	7 Days per Year
Arsenic	3×10^{-6}	7×10^{-7}	5×10^{-7}	1×10^{-5}	2×10^{-5}	4×10^{-7}
cPAHs (TEQ)	3×10^{-7}	2×10^{-8}	1×10^{-7}	2×10^{-6}	3×10^{-6}	8×10^{-8}
Total PCBs	6×10^{-7}	6×10^{-8}	2×10^{-7}	3×10^{-6}	6×10^{-6}	1×10^{-7}
PCBs (TEQ)	3×10^{-7}	4×10^{-8}	5×10^{-8}	1×10^{-6}	2×10^{-6}	3×10^{-8}
Dioxin/furan (TEQ)	6×10^{-7}	1×10^{-7}	NA	1×10^{-6}	2×10^{-6}	4×10^{-8}
Total TEQ excess cancer risk for dioxins/furans and coplanar PCBs	**9×10^{-7}**	**1×10^{-7}**	**NA**	**2×10^{-6}**	**4×10^{-6}**	**7×10^{-8}**
Total excess cancer risk (excluding PCB TEQ)[a]	**5×10^{-6}**	**9×10^{-7}**	**8×10^{-7}**	**2×10^{-5}**	**3×10^{-5}**	**6×10^{-7}**
Total excess cancer risk (excluding total PCBs)[a]	**4×10^{-6}**	**9×10^{-7}**	**7×10^{-7}**	**1×10^{-5}**	**3×10^{-5}**	**6×10^{-7}**

Notes:
Shaded cells indicate excess cancer risks greater than 1×10^{-6}.
a. Total risk values include the risks associated with all COPCs. However, only those COPCs with excess cancer risks greater than 1×10^{-6} for at least one scenario are listed in this table.

COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CT – central tendency
NA – not applicable (not a COPC)
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent

Contaminants with either an estimated excess cancer risk greater than 1 in 1,000,000 (1×10^{-6}) or a non-cancer HQ greater than 1 for at least one RME scenario were selected as COCs for the direct sediment contact exposure pathways. Based on these criteria, four contaminants were identified as COCs for direct sediment contact exposure (Table 3-3): arsenic for both RME scenarios and cPAHs, total PCBs, and total TEQ for clamming RME scenario.[28]

[28] Total TEQ is equal to the sum of PCB TEQ and dioxin/furan TEQ. When excess cancer risks for either PCB TEQ or dioxin/furan TEQ were not independently greater than 1×10^{-6}, the sum of these two chemicals (total TEQ) was identified as a COC if it was greater than this threshold.

3.2.3 Surface Water Exposure Scenarios

In addition to the seafood consumption and direct sediment contact scenarios, exposure to surface water in the EW was assessed for a swimming scenario, for which the exposure parameters were based on the adult swimming scenarios presented in the *King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay* (King County 1999). No RME level of exposure was defined because parameters used for this scenario likely result in significant overestimates of swimming exposure levels for the EW, given that they were developed for areas that include a greater number of recreational access points than the EW, and swimming in the EW will be limited because of a high concentration of large ship and tug boat traffic and cold water temperatures. Therefore, no COCs were identified based on exposure to surface water (Windward 2012b).

The only excess cancer risks that were greater than the 1×10^{-6} threshold were for PCB TEQ for both the high level of exposure (which assumed 2.4 hours of swimming, 24 days per year) and the medium level of exposure (which assumed 1 hour of swimming, 12 days per year) (equal to 9×10^{-6} and 2×10^{-6}, respectively). The total excess cancer risks (which includes all COPCs) for this scenario were also equal to 9×10^{-6} and 2×10^{-6}, respectively. No other COPCs (including total PCBs) had excess cancer risks greater than 1×10^{-6} or non-cancer HQs greater than 1 for any COPC-exposure level combination. As discussed in the EW HHRA (Windward 2012b), the PCB TEQ risk estimate is considered highly uncertain based on both current and anticipated future site use and on the uncertainty associated with the application of the dioxin-like TEQ approach for dermal exposure,[29] which contributed nearly all (over 99%) of PCB TEQ swimming risk (as compared with the incidental ingestion of water).

3.2.4 Sum of Risks for Multiple Exposure Scenarios

Risks for multiple scenarios were summed to represent the possible exposure of a single individual to EW COPCs during different activities. Summed risks (i.e., the sum of risks across pathways) are presented in Table 3-7 for the following multiple exposure scenarios:

- Adult tribal RME netfishing, adult tribal RME seafood consumption, and swimming

[29] The dioxin-like TEQ approach was developed for the consideration of the risk associated with the consumption of tissue (Van den Berg et al. 2006), and its applicability to dermal absorption exposure is uncertain because bioavailability for non-dietary exposures is not well characterized.

- Adult tribal CT netfishing, adult tribal CT seafood consumption, and swimming
- Adult tribal RME clamming, adult tribal RME seafood consumption, and swimming

Table 3-7

Excess Cancer Risk Estimates Across Scenarios

Activity	Excess Cancer Risk[a]
Adult Tulalip RME Combination Scenario	
Netfishing RME	5×10^{-6}
Swimming (medium level of exposure)	2×10^{-6}
Adult tribal RME seafood consumption based on Tulalip data	1×10^{-3}
Total	$\mathbf{1 \times 10^{-3}}$
Adult Tulalip CT Combination Scenario	
Netfishing CT	9×10^{-7}
Swimming (low level of exposure)	2×10^{-8}
Adult tribal CT seafood consumption based on Tulalip data	7×10^{-5}
Total	$\mathbf{7 \times 10^{-5}}$
Adult RME Clamming Combination Scenario	
Tribal clamming RME (120 days per year)	2×10^{-5}
Swimming (medium level of exposure)	2×10^{-6}
Adult tribal RME seafood consumption based on Tulalip data	1×10^{-3}
Total	$\mathbf{1 \times 10^{-3}}$

Notes:

a. For the seafood consumption and sediment exposure scenarios, total excess cancer risk estimates that excluded PCB TEQ were used because these were equal to or higher than total excess cancer risk estimates that excluded total PCBs. For swimming, the total excess cancer risk estimates that excluded total PCBs were used because they were higher than the total that excluded PCB TEQ.

CT – central tendency
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent

When estimated excess cancer risks were rounded to one significant figure, the sums for the three scenario groups above were the same as the estimates for the seafood consumption alone. Overall, swimming had the lowest risk estimates.

This analysis demonstrates that the contributions of netfishing, clamming, and swimming to estimated risks are relatively small in comparison with the contributions of seafood consumption, and it highlights the significance of the seafood consumption exposure pathway for all users of the EW.

3.2.5 Risk Driver COCs for Human Health

Risk drivers were identified from the COC list based on several considerations, including: 1) risk magnitude relative to acceptable risk thresholds (including a consideration of background concentrations, if applicable), 2) percent contribution to the total risk estimate, 3) detection frequency, and 4) other data quality or uncertainty considerations.

A subset of the COCs identified for the seafood consumption RME and direct sediment exposure RME scenarios were identified as risk drivers:

- **Seafood consumption scenarios** – Of the 12 COCs, 3 were identified as risk drivers (cPAHs [TEQ], PCBs,[30] and dioxins/furans [TEQ]).
- **Direct sediment exposure scenarios** – Of the four COCs, one was identified as a risk driver (arsenic).

A summary of risks for each COC, as well as a more detailed discussion of the selection of risk drivers, is presented in Table 3-8. Additional details regarding the selection of risk drivers are presented in Section B.7 of the EW HHRA (Windward 2012b). COCs not selected as risk drivers in the baseline HHRA are evaluated in Section 9 to assess the potential for risk reduction following remedial actions.

Table 3-8
COCs and Risk Drivers Selected for the EW HHRA

COC	Selection as Risk Driver and Summary of Rationale	
	Seafood Consumption RME Scenarios	**Direct Sediment Exposure RME Scenarios**
Arsenic	**NO** – risks greater than the upper end of EPA's acceptable risk range (1×10^{-4}); however, incremental risks were equal to or less than 1×10^{-6} because concentrations are similar to or lower than those in samples collected from background areas	**YES** – risk greater than the 10^{-6} threshold, percent contribution to the total risk (63% to 67%), and high detection frequency (70%)

[30] The consideration of PCBs as a risk driver is intended to account for both total PCBs and PCB (TEQ). It should be noted that risks for total PCBs were higher than those for PCB (TEQ) for all scenarios.

Table 3-8
COCs and Risk Drivers Selected for the EW HHRA

COC	Selection as Risk Driver and Summary of Rationale: Seafood Consumption RME Scenarios	Selection as Risk Driver and Summary of Rationale: Direct Sediment Exposure RME Scenarios
Cadmium	**NO** – HQ equal to 2 for the child tribal RME scenario based on Tulalip data; but considerable uncertainty is associated with this scenario, and HQs for total PCBs were over an order of magnitude higher	**NA** – not a COPC
cPAHs (TEQ)	**YES** – risks within EPA's acceptable risk range (up to 1×10^{-5}), percent contribution to the total risk (1% to 5%), and high detection frequency (71%)	**NO** – risks were only slightly greater than the 1×10^{-6} threshold
Total PCBs	**YES** – risks greater than the upper end of EPA's acceptable risk range (1×10^{-4}), percent contribution to the total risk (73% to 75%), and high detection frequency (98%)	**NO** – risks were only slightly greater than the 1×10^{-6} threshold
Pentachlorophenol[a]	**NO** – risk slightly greater than the 1×10^{-6} threshold for one of the three RME scenarios; contribution to the total excess cancer risk was less than 1%, and COC was detected in less than 4% of EW samples	**NA** – not a COPC
Pesticides[a,b]	**NO** – risks less than 1×10^{-5}, and each COC contributed less than 1% to the total excess cancer risk (combined contribution was less than 1.5% of the total)	**NA** – not a COPC
Dioxin/furan (TEQ)	**YES** – risks equal to the upper end of EPA's acceptable risk range (1×10^{-4}) and high detection frequency (100%)	**NO** – not a COC[c]
Total TEQ (sum of PCB TEQ and dioxin/furan TEQ)	**NA**[d]	**NO** – risks were only slightly greater than the 1×10^{-6} threshold

Notes:
a. Many of the analytical results upon which exposure point concentrations (EPCs) were based consisted of non-detects.
b. Five pesticides were identified as COCs for the seafood consumption scenarios: alpha-BHC, dieldrin, total chlordane, heptachlor epoxide, and mirex. It should also be noted that there is no evidence of historical use or manufacture of these pesticides in the EW.
c. See Section 6.3.3 of the SRI (Windward and Anchor QEA 2014) for information regarding the selection of COCs for the direct sediment exposure scenarios.
d. Total TEQ was considered only when neither PCB TEQ nor dioxin/furan TEQ independently qualified as a COC.

BHC – benzene hexachloride
COC – contaminant of concern
NA – not applicable
PCB – polychlorinated biphenyl

COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EW – East Waterway
RME – reasonable maximum exposure
SRI – Supplemental Remedial Investigation
TEQ – toxic equivalent

3.3 Risk-based Threshold Concentrations

For the EW, RBTCs are concentrations of risk driver COCs in sediment or tissue that are associated with specific risk estimates and exposure pathways. Cleanup of sediment to concentrations at or below a specific RBTC is predicted to be protective for the particular risk driver COCs, based on the exposure assumptions of the baseline risk assessments (Windward 2012a, 2012b). RBTCs for tissue and sediment were presented in Section 8 of the SRI (Windward and Anchor QEA 2014). Sediment RBTCs are used in this FS along with other information to establish PRGs (as presented in Section 4).

RBTCs for the human health risk driver COCs were calculated at three different excess cancer risk levels and for HQs equal to 1 (when the non-cancer hazard was greater than 1 in the HHRA) for both the direct contact with sediment scenarios (i.e., netfishing and tribal clamming) and the seafood consumption scenarios. The equations used to calculate the sediment RBTCs are based on the risk equations used in the baseline HHRA (Windward 2012b). RBTCs for ecological receptors were either based on TRVs used in the ERA or were based on Washington State SMS numeric sediment criteria (e.g., SQS).

3.3.1 RBTCs for Ecological Receptors

Risk driver COCs for ecological receptors include total PCBs for English sole and brown rockfish, TBT for benthic invertebrates, and 29 SMS contaminants with concentrations that exceeded the SQS in one or more surface sediment samples. The following describes the derivation of sediment RBTCs for these ecological risk driver COCs:

- **Total PCB RBTCs for fish** – Because of uncertainties in the study used to develop the tissue TRV for fish exposure to total PCBs, two tissue TRVs (520 and 2,640 µg/kg wet weight [ww]) were evaluated in the ERA (Windward 2012a), both of which were considered as tissue RBTCs. Sediment RBTCs for fish were then derived using the calibrated food web model (FWM) for the EW, as described in Section 8 of the SRI (Windward and Anchor QEA 2014). The sediment RBTC values ranged from 39 to greater than 470 µg/kg ww, depending on the tissue RBTC and species (Table 3-9).

Sediment RBTCs of greater than 470 µg/kg dw indicate that even under current conditions in the EW,[31] average tissue concentrations are estimated to be less than the tissue RBTC. This is consistent with the fact that average tissue concentrations in both species are less than the tissue TRV of 2,640 µg/kg ww. Only 4 out of the 15 individual rockfish samples and 7 out of 13 English sole whole-body composite tissue samples exceeded the tissue TRV of 2,640 µg/kg ww.

- **TBT RBTC for benthic invertebrates** – A sediment RBTC for TBT for the protection of the benthic invertebrate community was calculated using a biota-sediment accumulation factor (BSAF) developed using benthic invertebrate tissue and co-located sediment TBT and TOC concentrations from the EW. The sediment RBTC for TBT was 7.5 mg/kg OC, which results in a range of dry-weight sediment concentrations of 75 to 150 µg/kg dw for TOC values from 1% to 2%, which are typical TOC values for EW sediment.
- **RBTCs for SMS chemicals for benthic invertebrates** – Sediment RBTCs were set to the SQS and CSL sediment criteria from the SMS for the protection of benthic invertebrates (see Table 3-1 for these SMS values).

The sediment RBTCs derived for the risk driver COCs identified in the ERA are summarized in Table 3-9.

3.3.2 Sediment RBTCs for HHRA Direct Sediment Exposure Scenarios

Sediment RBTCs for the human health direct sediment contact exposure scenarios were calculated for arsenic for the three excess cancer risk levels (1×10^{-6}, 1×10^{-5}, and 1×10^{-4}; Table 3-10). Sediment RBTCs were not calculated for non-cancer hazards (at an HQ of 1) because all HQs were less than or equal to 1 for the RME scenarios in the HHRA (Windward 2012b).

3.3.3 Tissue RBTCs for HHRA Seafood Consumption Scenarios

Tissue RBTCs associated with the three RME seafood consumption scenarios were calculated for all three risk driver COCs (i.e., total PCBs, cPAHs, and dioxins/furans) for the three

[31] A sediment SWAC of 470 µg/kg dw was used in the FWM because it reflected the most current sediment interpolation at the time of model calibration.

Table 3-9
Sediment RBTCs for Ecological Risk Driver COCs

Risk Driver	Ecological Receptor	Sediment RBTC
Total PCBs	English sole	100 µg/kg dw (at tissue TRV of 520 µg/kg ww); >470 µg/kg dw[a] (at tissue TRV of 2,640 µg/kg ww)
	brown rockfish	39 µg/kg dw (at tissue TRV of 520 µg/kg ww); 458 µg/kg dw (at tissue TRV of 2,640 µg/kg ww)
TBT	benthic invertebrates	7.5 mg/kg OC, or 75 to 150 µg/kg dw (assuming 1 to 2% TOC)
29 SMS chemicals[b]	benthic invertebrates	SQS and CSL sediment criteria

Notes:

a. Sediment RBTC of >470 µg/kg dw indicate that under current conditions in the EW (the SWAC used in the calibrated FWM is equal to 470 µg/kg dw), average tissue concentration is estimated to be less than the tissue RBTC.

b. The 29 SMS chemicals identified as risk drivers are arsenic, cadmium, mercury, zinc, acenaphthene, anthracene benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo (a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,-c,d)pyrene, phenanthrene, pyrene, total benzofluoranthenes, HPAH, LPAH, bis(2-ethylhexyl) phthalate, butyl benzyl phthalate, di-n-butyl phthalate, 1,4-dichlorobenzene, 2-methylnaphthalene, 2,4-dimethylphenol, dibenzofuran, n-nitrosodiphenylamine, phenol, and total PCBs.

µg/kg – micrograms per kilogram
COC – contaminant of concern
CSL – cleanup screening level
dw – dry weight
FWM – food web model
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
OC – organic carbon
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SWAC – spatially-weighted average concentration
TBT – tributyltin
TOC – total organic carbon
TRV – toxicity reference value
ww – wet weight

Table 3-10
Sediment RBTCs for Human Health Risk Driver COC for RME Direct Sediment Exposure Scenarios

Risk Driver COC	Unit	Exposure Scenario	Sediment RBTCs: 10^{-6} (1 in 1,000,000) Risk Level	Sediment RBTCs: 10^{-5} (1 in 100,000) Risk Level	Sediment RBTCs: 10^{-4} (1 in 10,000) Risk Level
Arsenic	mg/kg dw	tribal clamming	1.3	13	130
		netfishing	3.7	37	370

Notes:

RBTCs were not calculated for non-cancer endpoints because estimated HQs were all < 1.

µg – micrograms
COC – contaminant of concern
dw – dry weight
mg/kg – milligrams per kilogram
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

excess cancer risk levels, and for total PCBs and dioxin/furan TEQ for a non-cancer HQ of 1 (Table 3-11). Tissue RBTCs associated with human seafood consumption scenarios were calculated in the SRI (Windward and Anchor QEA 2014) using rearrangements of the risk equations in the baseline HHRA (Windward 2012b); the risk equations and parameters used to calculate the tissue RBTCs are presented in Table 3-12. To derive the tissue RBTCs, these equations were solved for the concentration in seafood for a given target risk level using scenario-specific parameters (e.g., ingestion rates, body weights). As shown in Table 3-11, the tissue RBTCs for the adult tribal RME scenario based on Tulalip data were lower than those for the other RME scenarios for a given risk threshold for each risk driver COC.

Table 3-11
Ingestion-weighted Tissue RBTCs for the Human Health RME Seafood Consumption Scenarios

Risk Driver	Target Risk	Ingestion-weighted Tissue RBTC[a]			
		Excess Cancer Risk			Non-Cancer Hazard
		1×10^{-6}	1×10^{-5}	1×10^{-4}	HQ = 1
cPAHs[b] (µg TEQ/kg ww)	Adult Tribal RME (Tulalip Data)	0.84	8.4	84	NA
	Child Tribal RME (Tulalip Data)	0.85[c]	8.5[c]	85[c]	NA
	Adult API RME	2.9	29	290	NA
Dioxin/furan[d] (ng TEQ/kg ww)	Adult Tribal RME (Tulalip Data)	0.0056	0.056	0.56	NA[e]
	Child Tribal RME (Tulalip Data)	0.030	0.30	3.0	8.2
	Adult API RME	0.019	0.19	1.9	NA[e]
Total PCBs (µg/kg ww)	Adult Tribal RME (Tulalip Data)	0.42	4.2	42	17
	Child Tribal RME (Tulalip Data)	2.3	23	230	7.8
	Adult API RME	1.4	14	140	24

Notes:

a. Tissue RBTCs associated with human seafood consumption scenarios were calculated in the SRI (Windward and Anchor QEA 2014) using rearrangements of the risk equations in the baseline HHRA (Windward 2012b).
b. cPAHs are presented as benzo(a)pyrene TEQs.
c. Because of the potential for increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005), the risk estimate for children for cPAHs is based on dose adjustments across the 0-to-6-year age range of children (see Section B.5.1 of the HHRA for more information).
d. Dioxins/furans are presented as 2,3,7,8-TCDD mammalian TEQs.
e. An RBTC for dioxin/furan TEQ was only calculated for the child tribal RME scenario based on Tulalip data because it was the only RME scenario with an HQ > 1 for dioxin/furan TEQ.

µg – micrograms
API – Asian and Pacific Islanders
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
EPA – U.S. Environmental Protection Agency
NA – not applicable
ng – nanograms
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

HHRA – human health risk assessment
HQ – hazard quotient
kg – kilograms
mg – milligrams
SRI – Supplemental Remedial Investigation
TCDD – tetrachlorodibenzo-*p*-dioxin
TEQ – toxic equivalent
ww – wet weight

Table 3-12
Equations and Parameter Values for the Calculation of Tissue RBTCs

RBTC equation for carcinogenic effects:	RBTC equation for non-carcinogenic effects:
$$Tissue\ RBTC = \frac{TR}{\left(\left[\frac{IR \times FC \times EF \times ED \times CF}{BW \times AT_c}\right] \times SF\right)}$$	$$Tissue\ RBTC = \frac{THQ}{\left(\left[\frac{IR \times FC \times EF \times ED \times CF}{BW \times AT_{nc}}\right] \times \frac{1}{RfD}\right)}$$

Parameter Name	Acronym	Unit	Parameter Values[a]		
			Adult Tribal RME (Tulalip Data)	Child Tribal RME (Tulalip Data)	Adult API RME
Risk-based threshold concentration	RBTC	mg/kg ww	see Table 3-11 for calculated RBTCs		
Target excess cancer risk	TR	unitless	10^{-6}, 10^{-5}, 10^{-4}	10^{-6}, 10^{-5}, 10^{-4}	10^{-6}, 10^{-5}, 10^{-4}
Target HQ	THQ	unitless	1	1	1
Ingestion rate	IR	g/day	97.5	39.0	51.5
Fraction from contaminated site	FC	unitless	1	1	1
Exposure frequency	EF	days	365	365	365
Exposure duration	ED	years	70	6	30
Conversion factor	CF	kg to g	0.001	0.001	0.001
Body weight	BW	kg	81.8	15.2	63
Averaging time, cancer	AT_c	days	25,550	25,550	25,550
Averaging time, non-cancer	AT_{nc}	days	25,550	2,190	10,950
Slope factor	SF	$(mg/kg\text{-}day)^{-1}$	toxicity values are contaminant-specific (Total PCBs = 2; cPAH TEQ = 1; dioxin/furan TEQ = 150,000)		
Reference dose	RfD	mg/kg-day	toxicity values are contaminant-specific (Total PCBs = 0.00002; dioxin/furan TEQ = 7×10^{-10})		

Notes:
a. Parameter values are the same as those used in the LDW HHRA (Windward 2007a).

API – Asian and Pacific Islanders
cPAH – carcinogenic polycyclic aromatic hydrocarbon
g – gram
HHRA – human health risk assessment
HQ – hazard quotient
kg – kilogram
LDW – Lower Duwamish Waterway
mg – milligram
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
TEQ – toxic equivalent

The tissue RBTCs for the seafood consumption scenarios presented in Table 3-11 represent the ingestion-weighted average concentrations in tissue that correspond to a certain risk threshold for each scenario. For example, the RBTC for total PCBs for the adult tribal RME seafood consumption scenario based on Tulalip data is 4.2 µg/kg ww at the 1×10^{-5} excess cancer risk level. Thus, the consumption of 97.5 grams per day (g/day; the daily ingestion rate for the adult tribal RME scenario based on Tulalip data) of any tissue type with a total PCB concentration of 4.2 µg/kg ww for 70 years would result in a 1×10^{-5} excess cancer risk. The consumption of numerous types of seafood, such as crabs, clams, and fish (as specified in the exposure parameters for the adult tribal RME scenario based on Tulalip data), would also result in a 1×10^{-5} excess cancer risk as long as the ingestion-weighted average of the various tissue concentrations was 4.2 µg/kg ww. Thus, the tissue RBTCs presented in this section are not directly comparable with single species concentrations (e.g., the non-urban Puget Sound tissue concentrations presented in Section 7 of the SRI [Windward and Anchor QEA 2014]).

3.3.4 Sediment RBTCs for HHRA Seafood Consumption Scenarios

Sediment RBTCs for the human health seafood consumption exposure scenarios represent the sediment concentrations at which tissue concentrations equate to the targeted risk level. Thus, these RBTCs require developing a relationship between concentrations in sediment and tissue, as described below for each risk driver COC.

- **Total PCB sediment RBTCs** – A FWM calibrated for the EW (see Appendix C of the SRI; Windward and Anchor QEA 2014) was used to estimate the relationship between sediment and tissue concentrations for total PCBs, and to calculate sediment RBTCs. A range of RBTCs was calculated for each seafood exposure scenario using best estimate, upper bound, and lower bound parameter sets in the FWM. Sediment RBTCs for PCBs at the 1 in 1 million (1×10^{-6}) and 1 in 100,000 (1×10^{-5}) excess cancer risk levels and non-cancer risk of HQ = 1 for the tribal RME (adult and child) scenario could not be calculated; the contribution of total PCBs from water alone was high enough to result in excess cancer risks or non-cancer risk above those risk levels even in the absence of any contribution from sediment; the sediment RBTCs for these scenarios are expressed as "< 1" µg/kg dw in Table 3-13). At the 1 in 10,000 (1×10^{-4}) excess cancer risk level, sediment RBTCs for total PCBs ranged from 2 to 250 µg/kg dw for the three RME scenarios (Table 3-13). These sediment RBTCs for total PCBs are lower than the current

SWAC of total PCBs in the EW (approximately 470 µg/kg dw). It should be noted that sediment RBTCs for the lower risk levels (i.e., 1×10^{-5} and 1×10^{-6}) are especially difficult to quantify for several reasons. First, the FWM was calibrated for baseline conditions (i.e., a sediment concentration of 470 µg/kg PCBs), not post-remedy conditions that would be associated with lower concentrations and lower risk levels. The greater the difference between baseline and post-remedy conditions, the greater the uncertainty in the model application. Second, at the very low sediment total PCB concentrations associated with the low risk levels, the assumed total PCB concentration in water becomes increasingly important in affecting the modeling results, and the assumed post-remedy water value is also uncertain.

- **Dioxin/furan sediment RBTCs** – Dioxin/furan sediment RBTCs were developed using site-specific BSAFs for four species (English sole, brown rockfish, shiner surfperch, and crab), which were based on empirical data collected from the EW. BSAF values were calculated for a subset of four individual dioxin/furan congeners that were selected because they were the congeners that had the greatest contributions to the dioxin/furan TEQ values in tissues. Because BSAFs are specific to individual receptor species, it was necessary to convert the ingestion-weighted average tissue RBTCs presented in Table 3-11 to species-specific RBTCs. The main assumptions required for these calculations were the relative ingestion rates for the various items in the market basket diet and the relative tissue contaminant concentrations among the food items. Because both of these factors may change in the future, it is important to recognize that there is considerable uncertainty associated with the dioxin/furan sediment RBTCs based on these species-specific tissue RBTCs. At the 1×10^{-6} target risk level, the sediment RBTCs for the RME scenarios were less than 1 ng TEQ/kg dw (Table 3-13). At the 1×10^{-4} target risk level, sediment RBTCs for dioxin/furan TEQ ranged from 18 to 94 ng TEQ/kg dw for the three RME scenarios (Table 3-13). Details regarding the derivation of these sediment RBTCs are presented in Section 8 and Appendix C of the SRI (Windward and Anchor QEA 2014).
- **cPAH sediment RBTCs** – For cPAHs, 73% to 90% of the risk associated with seafood consumption for the RME scenarios is attributable to the consumption of clams. Thus, because of the importance of clam consumption in the cPAH TEQ risk estimate, the clam tissue-to-sediment relationship was evaluated to assess the potential for calculating sediment RBTCs. As discussed in Section 8.3.3 of the SRI (Windward and

Anchor QEA 2014), the clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop a sediment RBTC based on clam consumption. Variables other than localized sediment concentrations are likely to be important factors in determining tissue concentrations of cPAHs, based on the filter-feeding behavior of clams and, thus, any potential effect of sediment remediation on concentrations of cPAHs in clam tissue is highly uncertain. Long-term clam tissue monitoring following sediment remediation and source control will be needed to determine whether (and to what extent) decreases in cPAH concentrations in sediment result in decreases in cPAH concentrations in clam tissue.

Table 3-13
Sediment RBTCs for the HHRA RME Seafood Consumption Scenarios

Excess Cancer Risk Level[a]	Sediment RBTCs for the RME Scenarios		
	Adult Tribal RME (Tulalip data)	Child Tribal RME (Tulalip data)	Adult API RME
Total PCBs (µg/kg dw)[b]			
1×10^{-4}	2	250	100
1×10^{-5}	<1[c]	<1[c]	<1[c]
1×10^{-6}	<1[c]	<1[c]	<1[c]
HQ = 1	<1[c]	<1[c]	<1[c]
Dioxin/Furan TEQ (ng TEQ/kg dw)[d]			
1×10^{-4}	18	94	48
1×10^{-5}	1.8	9.4	4.8
1×10^{-6}	0.18	0.94	0.48
HQ = 1	n/c[e]	8.2	n/c[e]

Notes:

a. The clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop sediment RBTCs based on clam consumption (Section 3.3.4).
b. The RBTC was derived using the FWM parameter set that resulted in the closest match between empirical data and model estimates for all species.
c. Value could not be calculated because contribution from water alone resulted in estimated tissue concentrations greater than the applicable risk level, even in the absence of any contribution from sediment.
d. The RBTC is the mean of the RBTCs derived using site-specific BSAFs and tissue RBTCs derived for English sole, rockfish, shiner surfperch, and clams based on the market basket allocations for these species (see Section 8 of the SRI; Windward and Anchor QEA 2014).
e. An RBTC for dioxin/furan TEQ was only calculated for the child tribal RME scenario based on Tulalip data because it was the only RME scenario with an HQ > 1 for dioxin/furan TEQ.

µg/kg – micrograms per kilogram
API – Asian and Pacific Islander
BSAF – biota-sediment accumulation factor
n/c – not calculated
ng – nanograms
PCB – polychlorinated biphenyl

dw – dry weight
FWM – food web model
HHRA – human health risk assessment
HQ – hazard quotient
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
SRI – Supplemental Remedial Investigation
TEQ – toxic equivalent

3.4 Key Findings of the Baseline Risk Assessments

Key findings for the baseline ERA (Windward 2012a) are as follows:

- **Ecological risk driver COCs** – Risk driver COCs for ecological receptors include total PCBs for English sole and brown rockfish, TBTs for benthic invertebrates, and 29 SMS contaminants with concentrations that exceeded the SQS in one or more surface sediment samples.
- **Sediment RBTCs for ecological receptors** – Sediment RBTCs for the benthic invertebrate community were established at the SQS and CSL criteria of the SMS. Sediment RBTCs were derived using tissue TRVs and the calibrated EW FWM for fish and total PCBs, and were derived using site-specific BSAFs for TBT and benthic invertebrates (Table 3-9).
- **Potential for adverse effects in the benthic invertebrate community** – Comparison of sediment chemistry and site-specific toxicity test results with SMS indicated that no adverse effects on benthic invertebrates living in intertidal and subtidal sediments are predicted for approximately 38% of the EW area (i.e., the 59 acres in which contaminant concentrations were less than or equal to SQS chemical criteria or sediment was non-toxic according to SQS biological effects criteria). Minor adverse effects are predicted in approximately 23% of the EW area (36 acres), which had contaminant concentrations or biological effects in excess of the CSL values. The remaining 39% of the EW area (60 acres) had contaminant concentrations or biological effects between the SQS and CSL values, indicating the potential for minor adverse effects to benthic invertebrate communities.

Key findings for the baseline HHRA (Windward 2012b) are as follows:

- **Summary of risks** – The highest risks to people were associated with the consumption of resident seafood, including fish, crabs, and clams (Tables 3-4a and 3-4b). Lower risks were associated with activities that involve direct contact with sediment or surface water, such as clamming, netfishing, habitat restoration, or swimming (Table 3-6).
- **Risk driver COCs** – Arsenic was identified as a risk driver COC for human health based on direct sediment exposure, and PCBs, cPAHs, and dioxins/furans were

identified as risk driver COCs for human health based on seafood consumption (Tables 3-8 and 3-14). Arsenic was not identified as a risk driver for seafood consumption because, although total risk posed by arsenic was greater than the upper end of EPA's acceptable risk range, incremental risks were equal to or less than 1×10^{-6}.[32] This is because concentrations are similar to, or lower than, those in samples collected from background areas.

- **Sediment RBTCs for RME direct sediment contact scenarios** – Sediment RBTCs were calculated for arsenic (the risk driver COC) at all three excess cancer risk levels (Table 3-10).
- **Tissue RBTCs for RME seafood consumption scenarios** – Tissue RBTCs were calculated for PCBs, cPAHs, and dioxins/furans (the three risk driver COCs) at the three excess cancer risk levels. Tissue RBTCs were also calculated for PCBs and dioxins/furans based on the non-cancer threshold (Table 3-11).
- **Sediment RBTCs for the RME seafood consumption scenarios**:
  - **Total PCBs** – For total PCBs, sediment RBTCs were developed using a food web model for the EW and ranged from 2 to 250 µg/kg dw for the 1 in 10,000 (1×10^{-4}) excess cancer risk level for the three RME scenarios (Table 3-13). RBTCs for the 10^{-5} and 10^{-6} risk levels and the non-cancer RBTC for total PCBs for the RME seafood consumption scenarios were less than 1 µg/kg dw.
  - **Dioxins/furans** – For dioxins/furans, sediment RBTCs were estimated for each excess cancer risk level using site-specific BSAFs for four species (English sole, brown rockfish, shiner surfperch, and crab) and species-specific tissue RBTCs. Sediment RBTCs for the three RME scenarios were less than 1 ng TEQ/kg dw at the 1×10^{-6} target risk level and ranged from 18 to 94 ng TEQ/kg dw at 1×10^{-4} target risk level (Table 3-13).
  - **cPAHs** – For cPAHs, 73% or more of the risk associated with seafood consumption is attributable to the consumption of clams. Because the clam tissue-to-sediment contaminant concentration relationships in the SRI data were too uncertain to

[32] Details regarding the incremental risk evaluation can be found in Section B.5.5.1.2 of the East Waterway HHRA (Windward 2012b). This section discusses both the background arsenic dataset as well as the calculation of the incremental risks (i.e., the difference between risks estimates for the EW and those calculated for background areas).

support developing quantitative sediment RBTCs for cPAHs, sediment RBTCs were not derived.

The risk screening process used to identify COPCs, COCs, and risk drivers for human health and ecological receptors is summarized in Table 3-14. The COCs not selected as risk drivers are evaluated in Section 9 to assess the potential for risk reduction following remedial actions.

Table 3-14
Summary of Risk Screening and Identification of COCs and Risk Drivers

Chemical Category	Contaminants				
	Human Health Seafood Consumption	**Human Health Direct Sediment Contact**	**Human Health Direct Surface Water Contact**	**Benthic Invertebrate Community**	**Other Ecological Receptors**
STEP 1 – Conduct conservative risk-based screening to identify COPCs *Ecological: COPCs are contaminants with maximum exposure concentrations greater than TRVs or SQS.* *Human Health: COPCs are contaminants with maximum sediment or tissue concentrations greater than screening criteria.*					
COPCs	54 COPCs, including metals, PAHs, PCBs, dioxins/furans, organochlorine pesticides, and other SVOCs	**Netfishing** – 9 COPCs **Clamming** – 11 COPCs **Habitat Restoration** – 5 COPCs (COPCs included metals, PCBs, cPAHs, dioxins/furans, and other contaminants)	**Swimming** – 14 COPCs, including metals, PCBs, PAHs, and other SVOCs	**Benthic invertebrates** – 30 COPCs including metals, PAHs, PCBs, phthalates, and other SVOCs based on detected exceedance of SQS in surface sediment at one or more locations; total DDTs based on DMMP exceedance; naphthalene; TBT	**Crabs** – arsenic, cadmium, copper, mercury, zinc, TBT, and total PCBs **Fish** – arsenic, cadmium, chromium, copper, mercury, vanadium, total PCBs, TBT, benzo(a)pyrene, beta-endosulfan **Birds** –mercury, total PCBs, PCB TEQ, total TEQ **Mammals** – mercury, selenium, total PCBs, PCB TEQ, total TEQ
STEP 2 – Compare risk estimates to thresholds to identify COCs for both human health and ecological receptors *Ecological: COCs are contaminants with LOAEL-based HQs greater than or equal to 1.0 or greater than the SQS for benthic invertebrates.* *Human Health: COCs are contaminants with excess cancer risk estimates greater than 1 × 10^{-6} or an HQ greater than 1 for any RME scenario.*					
COCs	Arsenic, cadmium, cPAHs, PCP, PCBs, alpha-BHC, dieldrin, total chlordane, heptachlor epoxide, mirex, dioxins/furans	**Netfishing**[a] – arsenic **Clamming** –arsenic, cPAHs, PCBs, total TEQ	na	**Benthic invertebrates** – 30 COCs (based on SQS); total DDTs (based on DMMP); naphthalene; TBT	**Crabs** – cadmium, copper, and zinc **Fish** – cadmium, copper, vanadium, TBT, total PCBs

Table 3-14

Summary of Risk Screening and Identification of COCs and Risk Drivers

Chemical Category	Contaminants				
	Human Health Seafood Consumption	Human Health Direct Sediment Contact	Human Health Direct Surface Water Contact	Benthic Invertebrate Community	Other Ecological Receptors
STEP 3 – Apply weight-of-evidence approach to identify risk drivers *Ecological: Selection based on risk estimates, uncertainties discussed in the baseline ERA, and background considerations.* *Human Health: Selection based on magnitude of risk, relative percentage of total human health risk posed by the COC, and background considerations.*					
Risk drivers[b]	Total PCBs, cPAHs, dioxins/furans	Arsenic[c]	na	**Benthic invertebrates** – 29 COCs above SQS[d]; TBT	**Fish (English sole and brown rockfish)** – total PCBs

Notes:

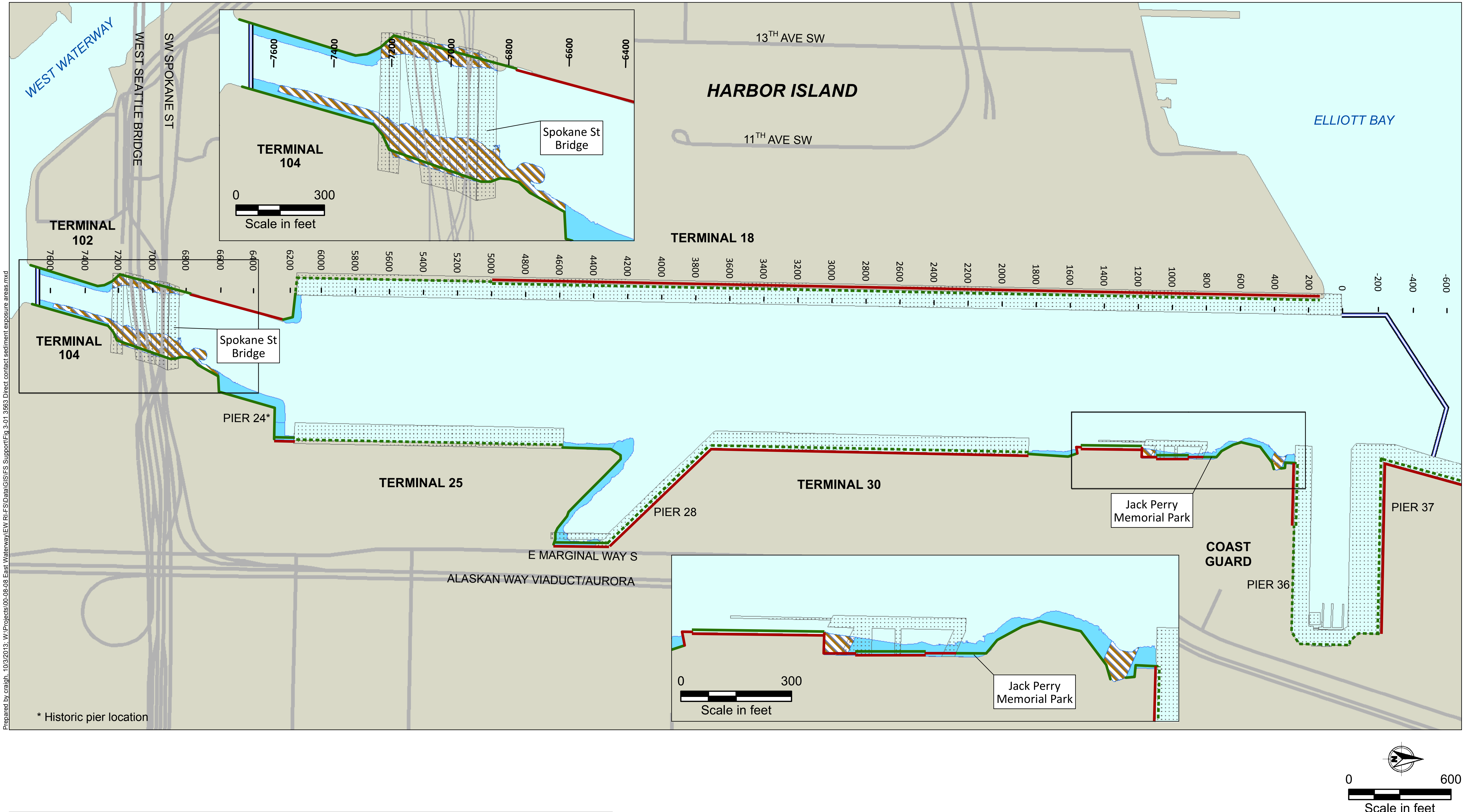
a. As noted in Table 3-3, cPAH TEQ was identified as a COC for netfishing in the HHRA. Subsequent to the HHRA, the cancer slope factor was updated in EPA's IRIS database for benzo[*a*]pyrene. This reduced the cPAH TEQ risks calculated in this FS as compared with those in the HHRA (Windward 2019). The updated cPAH TEQ netfishing risks for the RME scenario are below 1×10^{-6} , meaning cPAH TEQ is not a COC for the netfishing scenario. Thus, cPAH TEQ is not included in analyses for the netfishing scenario in the remainder of the FS.

b. COCs that were not selected as risk drivers are evaluated to assess the potential for risk reduction following remedial actions; this evaluation is presented in Section 9.

c. As noted in Table 3-3, cPAH TEQ was identified as a risk driver for clamming and netfishing in the HHRA. Subsequent to the HHRA, the cancer slope factor was updated in EPA's IRIS database for benzo[*a*]pyrene. This reduced the cPAH TEQ risks calculated in this FS as compared with those in the HHRA (Windward 2019). Based on the updated cPAH TEQ risks for the RME scenarios,cPAH TEQ is not a COC (and thus not a risk driver) for netfishing direct contact scenario and cPAHs is not a risk driver for the clamming direct contact scenario. Thus, cPAH TEQ is not included in analyses for direct contact scenarios in the remainder of the FS.

d. The 29 SMS chemicals identified as risk drivers are arsenic, cadmium, mercury, zinc, acenaphthene, anthracene benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo (a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,-c,d)pyrene, phenanthrene, pyrene, total benzofluoranthenes, HPAH, LPAH, bis(2-ethylhexyl) phthalate, butyl benzyl phthalate, di-n-butyl phthalate, 1,4-dichlorobenzene, 2-methylnaphthalene, 2,4-dimethylphenol, dibenzofuran, n-nitrosodiphenylamine, phenol, and total PCBs.

BHC – benzene hexachloride
COC – contaminant of concern
COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredged Material Management Program
ERA – ecological risk assessment
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
HQ – hazard quotient
LOAEL – lowest-observed-adverse-effect level
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
PCP – pentachlorophenol
RBC – risk-based concentration
RME – reasonable maximum exposure
RSL – regional screening level
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SVOC – semivolatile organic compound
TBT – tributyltin
TEQ – toxic equivalent
TRV – toxicity reference value



Sheetpile wall
Exposed riprap
Covered riprap
Sheetpile wall and exposed riprap
Sheetpile wall and covered riprap
Non-tribal clamming areas (public access from upland or walking at low tide)
Tribal clamming and habitat restoration areas (in addition to non-tribal clamming areas)
Dock/Pier/Bridge
Road
East Waterway Study Area Boundary

Figure 3-1
East Waterway HHRA Direct Sediment Exposure Areas
Feasibility Study
East Waterway Study Area

4 REMEDIAL ACTION OBJECTIVES AND PRELIMINARY REMEDIATION GOALS

This section identifies narrative RAOs and numerical PRGs for cleanup of the EW. RAOs for the EW describe goals for the protection of human health and the environment (EPA 1999a). 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).

The step of identifying narrative RAOs provides a transition between the findings of the human health and ecological risk assessments and development of remedial alternatives in the FS. The RAOs pertain to the specific exposure pathways and receptors evaluated in the risk assessments and for which unacceptable risks were identified.

RAOs are developed herein for cleanup of contaminated sediment in the EW. Surface water is also a medium of concern because risks to human health and ecological receptors are created by hazardous substances in the water column in addition to those in sediments. However, no active remedial measures are anticipated solely for the water column. Nevertheless, significant improvements in surface water quality are expected following sediment cleanup and implementation of upland source control measures. Further, water quality monitoring will be part of long-term monitoring for the site.

PRGs are intended to protect human health and the environment and to comply with ARARs for specific contaminants (EPA 1991a). For the EW, PRGs are numerical concentrations or ranges of concentrations in sediment that protect a particular receptor from exposure to a risk driver COC by a specific pathway. The PRGs are expressed as sediment concentrations for the identified risk driver COCs because the alternatives in this FS address cleanup of contaminated sediments. Although ARARs are identified in this FS for surface water, PRGs are not developed for surface water because actions to directly address water quality are not included among the FS alternatives.

4.1 Applicable or Relevant and Appropriate Requirements

CERCLA Section 121(d) requires remedial actions to comply with (or formally waive) ARARs, which are defined as any legally applicable or relevant and appropriate standard, requirement, criterion, or limitation under any federal environmental law, or promulgated under any state environmental or facility siting law that is more stringent than the federal requirements. This subsection identifies ARARs for cleanup of the EW. Section 9 of this document evaluates whether the remedial alternatives developed for cleanup of the EW comply with these ARARs.

The NCP (40 CFR 300.5) defines applicable requirements as the more stringent among those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances found at a CERCLA site. A requirement may not be applicable, but nevertheless may be relevant and appropriate.

Table 4-1 lists and summarizes ARARs identified for the EW OU. Some ARARs prescribe minimum numerical requirements or standards for specific media such as sediment, surface water, and groundwater. Other ARARs place requirements or limitations on actions that may be undertaken as part of a remedy.

Some ARARs contain numerical values or methods for developing such values. These ARARs establish minimally acceptable amounts or concentrations of hazardous substances that may remain in or be released to the environment, or minimum standards of effectiveness and performance expectations for the remedial alternatives. RBTCs based on risks to human health or the environment may dictate setting more stringent standards for remedial action performance, but they cannot be used to relax the minimum legally prescribed standards in ARARs (EPA 1991a). The rest of this subsection focuses on ARARs containing specific minimum numerical standards.

Washington State has enacted environmental laws and promulgated regulations to implement or co-implement several major federal laws through federally approved programs, such as the CWA, Clean Air Act, and RCRA. Washington's state cleanup law, MTCA, is an ARAR for the EW OU, and sediment sites under MTCA are regulated by SMS, which promulgates methods for developing and complying with cleanup levels. The PRGs are developed in Sections 4.3 and 4.4 to comply with SMS.

Table 4-1
ARARs for the East Waterway[a]

Topic	Threshold	Regulatory Citation: Federal	Regulatory Citation: State	Comment
Soil, Groundwater, Surface Water and Air Quality	Cleanup standards for multiple media	–	Model Toxics Control Act (MTCA) (Chap. 70.105D RCW; WAC 173-340)	MTCA established excess cancer risk standards, among other important standards.
Sediment Quality	Sediment cleanup standards	–	Sediment Management Standards (SMS) (WAC 173-204)	The SMS are promulgated rules under MTCA for excess human health cancer risk standards, non-cancer risk standards for human health and higher trophic level species, and numerical criteria for the protection of benthic community.
Surface Water Quality	Surface water quality standards	National Recommended Ambient Water Quality Criteria established under Section 304(a) of the Clean Water Act (33 USC 1251 et seq), water.epa.gov/scitech/swguidance/ standards/criteria/index.cfm	Surface Water Quality Standards (RCW 90.48; WAC 173-201A) State Aquatic Life Criteria (National Toxics Rule 40 CFR 131.36(b)(1) as applied to Washington per 40 CFR 131.36(d)(14) State Human Health Criteria)	National Recommended Federal Water Quality Criteria established under Section 304(a) of the Clean Water Act are relevant and appropriate. More stringent State surface water quality standards apply where the State has adopted, and EPA has approved, Water Quality Standards. Both chronic and acute standards are used.
Land Disposal of Waste	Disposal of materials containing polychlorinated biphenyls	Toxic Substances Control Act (TSCA) (15 USC 2605; 40 CFR Part 761)	–	None found to date that exceed TSCA levels
	Hazardous waste	Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions (42 USC 6901-92k)	Dangerous Waste Regulations Land Disposal Restrictions (RCW 70.105; WAC 173-303, -140, -141)	None found to date that exceed RCRA levels
Waste Treatment Storage and Disposal	Disposal limitations	RCRA (42 USC 6901-6992k; 40 CFR 260-279)	Dangerous Waste Regulations (RCW 70.105; WAC 173-303)	–
Noise	Maximum noise levels	–	Noise Control Act of 1974 (RCW 70.107; WAC 173-60)	–
Groundwater	Groundwater quality	Safe Drinking Water Act Maximum Contaminant Levels and non-zero Maximum Contaminant Level Goals (40 CFR 141)	RCW 43.20A.165 and WAC 173-290-310	For on-site potable water, if any.
Dredge/Fill and Other In-water Construction Work	Discharge of dredged/fill material into navigable waters or wetlands	Clean Water Act (Sections 401, 404; 33 USC 1341-1344; 40 CFR 121.2, 230, 231; 33 CFR 320, 322-3, 328-30); Rivers and Harbors Act (33 USC 401 et seq)	Hydraulic Code Rules (RCW 75.55; WAC 220-110)	For in-water dredging, filling, or other construction.
	Open-water disposal of dredged sediments	Marine Protection, Research and Sanctuaries Act (33 USC 1401-1445; 40 CFR 227)	Dredged Material Management Program (RCW 79.105.500; WAC 332-30-166 (3))	–
Solid Waste Disposal	Requirements for solid waste handling, management, and disposal	Solid Waste Disposal Act (42 USC 6901-92k; 40 CFR 257, -258)	Solid Waste Handling Standards (RCW 70.95; WAC 173-350)	–
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)	–
Shoreline	Construction and development	–	Shoreline Management Act (RCW 90.58; WAC 173-16)	For construction within 200 feet of the shoreline.
Floodplain Protection	Avoid adverse impacts, minimize potential harm	Executive Order 11988, Protection of flood plains (40 CFR 6, Appendix A); Federal Emergency Management Agency National Flood Insurance Program Regulations (44 CFR 60.3(d)(3))	Growth Management Act critical areas	For in-water construction activities, including any dredge or fill operations. Includes local ordinances: KCC Title 9 and SMC 25.09.
Critical (or Sensitive) Area	Evaluate and mitigate impacts	–	Growth Management Act (RCW 36.70A)	–

Table 4-1
ARARs for the East Waterway[a]

Topic	Threshold	Regulatory Citation: Federal	Regulatory Citation: State	Comment
Habitat for Fish, Plants, or Birds	Evaluate and mitigate habitat impacts	Clean Water Act (Section 404 (b)(1)); 1981 U.S. Fish and Wildlife Mitigation Policy (44 CFR 7644-7663)[b]; U.S. Fish and Wildlife Coordination Act (16 USC 661 et seq); Migratory Bird Treaty Act (16 USC 703-712)	–	–
Pretreatment Standards	National pretreatment standards	–	40 CFR Part 403; Metro District Wastewater Discharge Ordinance (KCC) to be considered (as a local requirement)	–
Native American Graves and Sacred Sites	Evaluate and mitigate impacts to cultural resources	Native American Graves Protection and Repatriation Act (25 USC 3001 et seq.; 43 CFR Part 10) and American Indian Religious Freedom Act (42 USC 1996 et seq.)	–	–
Critical Habitat for Endangered Species	Conserve endangered or threatened species, consult with species listing agencies	Endangered Species Act of 1973 (16 USC 1531 et seq; 50 CFR 200, -402); Magnuson-Stevens Fishery Conservation and Management Act (16 USC 1801-1884)	Endangered, threatened, and sensitive wildlife species classification (WAC 232-12-297)	Consult and obtain Biological Opinions.
Historic Sites or Structures	Requirement to avoid, minimize, or mitigate impacts to historic sites or structures	National Historic Preservation Act (16 USC 470f; 36 CFR Parts 60, 63, and 800)	–	Considered if implementation of the selected remedy involves removal of historic sites or structures.

Notes:

a. The East Waterway is being remediated under CERCLA and will comply with CERCLA requirements and guidance. ARARs are requirements other than CERCLA.

b. To-Be-Considered criterion does not qualify as an ARAR.

ARAR – Applicable or relevant and appropriate requirement
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CFR – Code of Federal Regulations
EPA – U.S. Environmental Protection Agency
KCC – King County Code
RCW – Revised Code of Washington
SMC – Seattle Municipal Code
USC – United States Code
WAC – Washington Administrative Code

Recommended federal WQC developed to protect ecological receptors and human consumers of fish and shellfish are relevant and appropriate requirements pursuant to CERCLA Section 121 (d)(2)(A)(ii) and RCW 70.105D.030(2)(e). Although ambient water quality criteria for organisms only are an ARAR for the EW, ambient water quality criteria for consumption of organisms and water are not relevant because the EW is not a source of drinking water. Under CERCLA, state water quality standards (WQS) approved by EPA are generally applicable requirements under the CWA. National recommended federal WQC established pursuant to Section 304(a)(1) of the CWA are compiled and presented on the EPA website at http://www.epa.gov/waterscience/criteria/wqctable/. Although these criteria are advisory for CWA purposes (to assist states in developing their standards), the last sentence of CERCLA Section 121(d)(2)(A)(ii) makes them generally relevant and appropriate requirements for CERCLA site remedial actions.

Consequently, the more stringent of the recommended federal marine WQC and the state marine WQS are ARARs for the site. Washington State WQS for the protection of aquatic life found at WAC 173-201A-240 meet the federal requirements of Section 303(c)(2)(B) of the CWA and are at least as stringent as the recommended federal WQC. Furthermore, in Washington State, an antidegradation policy helps prevent unnecessary lowering of water quality (WAC 173-201A-300 through WAC 173-201A-410). It is also recognized that portions of many waterbodies cannot meet the assigned criteria due to the natural conditions of the waterbody. Per WAC 173-201A-260, when a waterbody does not meet its assigned criteria due to human structural changes that cannot be effectively remedied (as determined consistent with the federal regulations at 40 CFR 131.10), then alternative estimates of the attainable water quality conditions, plus any further allowances for human effects specified in this section for when natural conditions exceed the criteria, may be used to establish an alternative criteria for the waterbody (see WAC 173-201A-430 and 173-201A-440).[33] Therefore, toxic, radioactive, or deleterious material concentrations must be below those which have the potential, either singularly or cumulatively, to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health (see WAC 173-201A-240, toxic substances, and 173-201A-250, radioactive substances).

[33] Alternative criteria have not been developed for the EW at this time.

4.2 Development of Remedial Action Objectives

The RAOs are narrative statements that describe specific goals for protecting human health and the environment. RAOs describe in general terms what the cleanup will accomplish for the EW. RAOs help focus the development and evaluation of remedial alternatives and form the basis for establishing PRGs. EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988) specifies that RAOs are to be developed based on the results of the HHRA and ERA. Other EPA guidance (EPA 1991b, 1999a) states that RAOs should specify the following:

- The exposure pathways, receptors, and COCs
- An acceptable concentration or range of concentrations for each exposure pathway

Section 2 summarized the SRI, including the chemical and physical CSM. Section 3 summarized the results of the risk assessments, which identified receptors, exposure pathways, risk driver COCs, and, where calculable, RBTCs. The RAOs presented here were crafted based on the SRI and findings from the baseline ERA (Windward 2012a) and HHRA (Windward 2012b).

4.2.1 Remedial Action Objectives for the East Waterway Operable Unit

The results of the baseline HHRA and ERA indicate that remedial action is warranted to reduce unacceptable human health and ecological risks posed by COCs in the EW OU. Unacceptable risks were estimated for certain human health exposure scenarios (through seafood consumption and direct contact exposure pathways) and for certain ecological risks (for benthic organisms and for other ecological receptors).

For human health, EPA defines a generally acceptable risk range for excess cancer risks as between 1 in 10,000 (1×10^{-4}) and 1 in 1 million (1×10^{-6}) (i.e., the "target risk range"), and for non-cancer risks, an HI[34] of 1 or less is considered acceptable (EPA 1991b). Excess cancer risks greater than 10^{-4} or HIs greater than 1 generally warrant a response action (EPA 1997b).

[34] HIs are calculated as the sum of hazard quotients with similar non-cancer toxic endpoints. HIs include both background and site-specific exposures, so achieving an HI of less than 1 may not be possible in some cases.

Appendix A details how cleanup levels are established under SMS. The SMS consider individual excess cancer risk RBTCs (one COC at a time) of no greater than 1×10^{-5} to achieve the CSL and 1×10^{-6} to achieve the SCO, and total excess cancer risks (all carcinogens combined) of no greater than 1×10^{-5} (to achieve both the SCO and CSL). For non-cancer risks, SMS consider RBTCs based on an HQ of 1 for individual contaminants and an HI of 1 for multiple contaminants with similar types of toxic action (to achieve both the SCO and the CSL).

Both CERCLA and SMS also consider background concentrations and PQLs when developing cleanup levels, as discussed in Sections 4.3 and 4.4.

Based on guidance provided under CERCLA and other requirements provided in MTCA/SMS, four RAOs have been identified for the cleanup of EW sediments. These RAOs, which are preliminary and will be finalized in the ROD, are identified below, and a discussion of each RAO follows.

RAO 1: Reduce risks associated with the consumption of contaminated resident EW fish and shellfish by adults and children with the highest potential exposure to protect human health.

Lifetime excess cancer risks from human consumption of resident EW seafood are estimated to be greater than 1×10^{-5} for some individual carcinogens, and greater than 1×10^{-4} for carcinogens cumulatively under RME seafood consumption scenarios. In addition, the estimated non-cancer risks exceed an HI of 1 (see Table 3-4b). These estimated risks warrant response actions to reduce exposure.

Total PCBs, cPAHs, and dioxins/furans are the primary risk driver COCs that contribute to the estimated risks based on consumption of resident seafood. Achieving RAO 1 requires that site-wide average[35] concentrations of COCs in sediment or bioavailability be reduced, which, in conjunction with source control, is expected to reduce COC concentrations in water and

[35] The FS uses average concentrations to evaluate the effectiveness of alternatives in attaining RAOs. In practice, compliance with cleanup levels will be based on the 95% upper confidence limit on the mean (UCL95).

fish and shellfish tissue. Surface water will not be directly remediated in the EW OU but will be improved by implementation of the selected remedy and by source control.

Exposure of fish and shellfish to COCs in sediment occurs within the biologically active zone. As reported in the SRI (Windward and Anchor QEA 2014), this zone is estimated to be the upper 10 cm of sediment so that is the point of compliance for this RAO. Deeper, undisturbed sediments contribute negligibly to the risks addressed by this RAO if contaminants in these deeper sediments do not migrate into or are exposed to the biologically active zone. However, as discussed in Section 2.11, shallow subsurface contamination may be incorporated into the biologically active zone due to vessel scour[36] in some areas and, therefore, may need to be addressed to achieve this RAO. RAO 1 refers to resident fish and shellfish, which spend an extensive amount of time in the EW and tend to accumulate certain hazardous substances. However, anadromous fish are not included because they spend most of their lives outside the EW and do not accumulate significant amounts of hazardous substances from the EW.

With regard to seafood consumption, bioaccumulative COCs enter the food web from both sediment and water. For example, the food web model used to predict tissue PCB concentrations (refer to Appendix C of the SRI; Windward and Anchor QEA 2014) assumes that the exposure of fish and shellfish to PCBs occurs through their exposure to both sediments and surface water.

The objective of sediment remediation is to reduce risk from seafood consumption to meet the regulatory thresholds established (in this case, 1×10^{-6} for individual carcinogens, 1×10^{-5} for multiple carcinogens, and non-cancer risks of HI of 1; or to background or PQL concentrations). Sediment remediation will target background concentrations or PQLs if sediment concentrations related to risk thresholds noted above are below those levels (Section 4.3.3).

[36] Erosion from possible slumping/sloughing of slopes, erosion and mixing due to bioturbation and tidal flow, and erosion from potential seismic activity are minimal in comparison to vessel impacts in the EW.

Substantial reductions in the concentrations of such COCs in sediment achieved through remediation should also reduce the concentrations of those COCs in surface water, thereby contributing to reducing their concentrations in fish and shellfish tissue and ultimately reducing human health risks. The relationships between sediment, surface water, and tissue concentrations are complex, and will be assessed through long-term monitoring of the remedial actions. Institutional controls, such as seafood consumption advisories, public outreach, and education are anticipated to be necessary, depending on the human health risks following remediation.

RAO 2: Reduce risks from direct contact (skin contact and incidental ingestion) to contaminated sediments during netfishing and clamming to protect human health.

Lifetime excess cancer risks from human direct contact (which includes incidental sediment ingestion and dermal contact with sediment) RME scenarios (netfishing and tribal clamming) are estimated to be within EPA's 10^{-4} to 10^{-6} target risk range (Table 3-6) for the individual risk driver COCs. Some individual excess cancer risks exceed 1×10^{-5}, and total risks from all risk driver COCs exceed 1×10^{-5}, both of which are SMS thresholds. Therefore, the risks associated with these exposure pathways warrant response actions to reduce exposure.

Arsenic was identified as a risk driver based on its excess cancer risk (above the applicable thresholds), contribution to the overall excess cancer risk (these COCs contributed the majority of the risk), and high detection frequency (greater than 80%). No HIs were greater than 1 for any of the direct contact RME scenarios, and thus there are no COCs or risk drivers for non-cancer risks based on direct contact.

Achieving RAO 2 requires that average concentrations of COCs be reduced at locations and depths within the sediment where people have the potential to be exposed. For netfishing activities, exposure is over the entire EW and to surface sediments (0 to 10 cm). Direct contact risks in the clamming areas are assumed to result from exposure to the upper 25 cm[37]

[37] The use of the 25-cm depth in the intertidal areas was based on site-specific clam burrowing depths for clam species collected in the EW (less than 30 cm for butter clams, less than 10 cm for littleneck clams, and approximately 10 cm for cockles), consistent with Pacific Northwest-specific information (Kozloff 1973). The

depth interval, which accounts for potential exposures to clammers, who may dig holes deeper than 10 cm. Deeper sediments in other areas do not contribute appreciably to these risks unless they could be exposed by future disturbances (e.g., erosion, propeller scour, earthquakes). However, as discussed in Section 2.11, shallow subsurface contamination may be incorporated into the biologically active zone primarily due to vessel scour[38] in some areas (Figure 2-15) and, therefore, may need to be addressed to achieve this RAO.

The objective of sediment remediation is to reduce risk from direct contact to meet the regulatory risk thresholds established (in this case, 1×10^{-6} for individual carcinogens, 1×10^{-5} for multiple carcinogens; or to background concentrations). Sediment remediation will target background concentrations if sediment concentrations related to risk thresholds are below background concentrations (Section 4.3.3). Institutional controls, such as public outreach and education, may be necessary to further reduce risk, depending on the potential human health risks following remediation.

RAO 3: Reduce to protective levels risks to benthic invertebrates from exposure to contaminated sediments.

The SMS provide both chemical and biological effects-based criteria for benthic invertebrates. The numerical SMS chemical criteria are available for 47 contaminants or groups of contaminants (i.e., SQS and CSL). These numerical chemical criteria are based on AETs developed for four different benthic endpoints by the Puget Sound Estuary Program (Barrick et al. 1988). An AET is the concentration of a specific contaminant above which a significant adverse biological effect was always found among the several hundred samples used in its derivation. In general, the lowest of the four AETs for each contaminant was identified as the SQS; the second lowest AET was identified as the CSL. According to the SMS, locations with all contaminant concentrations less than or equal to the SQS are defined as having no acute or chronic adverse effects on biological resources, locations with any contaminant concentrations between the SQS and the CSL are defined as having the

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25-cm depth provides a good estimate of the average depth to which individuals might dig to collect intertidal clams.

[38] Erosion from potential slumping/sloughing of slopes, erosion and mixing due to bioturbation and tidal flow, and erosion from potential seismic activity are minimal in comparison to vessel impacts in the EW.

potential for minor adverse effects, and locations with any contaminant concentration greater than the CSL are defined as having a likelihood of having minor adverse effects (refer to Section 5 of the SRI; Windward and Anchor QEA 2014).

The baseline ERA (Windward 2012a) reported that 29 contaminants were detected in surface sediment at one or more locations within the EW at concentrations exceeding their respective SQS (see Table 3-1). Thus, the ERA determined that these 29 contaminants are COCs because they pose a risk to the benthic invertebrate community. These 29 COCs are designated as risk drivers for this pathway. In addition, the ERA identified TBT as a COC for benthic invertebrates because of LOAEL-based HQs greater than 1, and TBT is also designated as a risk driver for the benthic invertebrate community.

Benthic organisms reside primarily in the biologically active zone (uppermost 10 cm) of intertidal and subtidal sediments of the EW OU (Section 2 of the SRI; Windward and Anchor QEA 2014). Deeper sediments in areas subject to disturbance (e.g., from erosion, propeller scour, and earthquakes) that contain COCs at concentrations above the SQS may warrant response actions to maintain compliance in the biologically active zone.

RAO 4: Reduce to protective levels risks to crabs and fish from exposure to contaminated sediment, surface water, and prey.

Total PCBs were identified as a risk driver COC for English sole and brown rockfish because PCBs in fish tissue exceeded the two LOAEL TRVs that were associated with adverse effects (Section 3.1.3). Three COCs were identified for crab but not determined to be risk driver COCs (see Table 3-2). No adverse effects are expected for birds or mammals because no contaminants of potential concern have concentrations exceeding the relevant threshold concentrations, and thus there are no COCs for these receptors. Thus, achievement of RAO 4 is based on addressing PCB risk to fish.

Fish are indirectly exposed to PCBs in sediment primarily through the consumption of prey. Therefore, reductions in site-wide average concentrations of PCBs in sediment through remedial action should reduce PCB concentrations in fish. The potential for exposure of prey to COCs occurs primarily within the biologically active zone (upper 10 cm of sediment).

Deeper sediments, if left undisturbed, contribute negligibly to the risks addressed by this RAO. Deeper sediments in areas subject to disturbance (e.g., from erosion, propeller scour, and earthquakes) that contain COCs at concentrations above an action level designed to achieve the RAO 4 PRGs may warrant response actions to maintain compliance in the biologically active zone.

Expected improvements to surface water quality will be achieved through remediation of site sediments; no active remediation of surface water is anticipated. Remediation will reduce COC concentrations in the EW OU sediments; this in turn should also reduce those same COC concentrations in surface water, thereby contributing to a reduction of their concentrations in fish tissue (including prey species). The relationships between sediment, surface water, and tissue concentrations are complex, and will be assessed through long-term monitoring following completion of the remedial actions.

4.2.2 Role of Source Control

Active sediment remediation of COCs that have previously accumulated in sediments over time will initially address a major portion of the risks addressed in each RAO. However, the presence of ongoing contaminant source inputs will affect the long-term equilibrium concentrations that can be expected to be achieved over time within the EW OU sediments. Source control activities that are ongoing or that will occur in the future will reduce lateral source inputs to the EW and tend to lower these long-term equilibrium concentrations and reduce the extent of recontamination that will occur in sediments. The recontamination predictions included in the FS provide a basis for understanding how the ongoing source inputs may impact the remedial decision for the EW. The recontamination predictions in Section 4 of Appendix J indicate that an analysis of source control alternatives is not needed in this FS, and that specific source control remedial actions will not be specified in the Proposed Plan or ROD.

The SRI included characterization of each of the different pathways by which ongoing contaminant sources could potentially recontaminate EW sediments, as described in the FS in Section 2.11.3. This FS includes recontamination predictions that evaluate the potential impact of ongoing direct discharges and the transport of upstream inputs on EW sediment quality.

As described in Section 2.12, multiple existing source control programs are currently operating within the EW OU and its watersheds. These programs include the work of the Port, City, and County, as well as the work of multiple regulatory agencies (e.g., Ecology, PSCAA, and EPA). Collectively, this source control work includes actions being taken under multiple programs and regulatory authorities.

Ongoing source control activities will assist in completing the following:

- Reduce the potential for contaminants in sediments to exceed the EW RALs to be established in the ROD with a long-term goal of achieving the site PRGs.
- Achieve adequate source control to allow sediment cleanup to be implemented.
- Support long-term suitability and success of current and future habitat restoration opportunities.

Source control is an ongoing, iterative process that continually produces new information and actions.

4.3 Process for Development of Preliminary Remediation Goals

PRGs are the COC 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 1997b). The PRGs are used in the FS to guide evaluation of proposed remedial alternatives, but they are not the final CERCLA cleanup levels. EPA will ultimately select those levels in the ROD. This section summarizes the process for development of PRGs, which will be used by EPA to determine sediment cleanup levels and performance standards for the EW OU.

PRGs are developed for each risk driver COC, and are expressed as sediment concentrations that are intended to achieve the corresponding RAO. PRGs are based on consideration of the following factors:

- ARARs, including SMS cleanup level development requirements
- RBTCs based on the human health and ecological risk assessments
- Background concentrations if protective RBTCs are below background concentrations
- Analytical PQLs if protective RBTCs are below concentrations that can be quantified by chemical analysis

This section presents the numerical criteria in these categories to enable a comprehensive analysis and identification of PRGs. The pertinent information is then compiled and numerical PRGs are identified for each risk driver COC and each RAO.

4.3.1 Role of ARARs

Under CERCLA, ARARs are any standard, requirement, criteria, or limitation under federal environmental law or more stringent promulgated standard, requirement, criteria or limitation under State environmental or facility siting law that is legally "applicable" to the hazardous substance (or pollutant or contaminant) concerned or is "relevant and appropriate" under the circumstances of the release. Important federal and state ARARs for development of EW cleanup levels include federal AWQC and the Washington State SMS, MTCA, and water quality standards.

The SMS established requirements for remediation of contaminated sediments. PRGs are developed to protect human health, the benthic community, and higher trophic level species. PRGs developed for RAOs 1 and 2 are consistent with the SMS for protection of human health, PRGs developed for RAO 3 are consistent with the SMS for protection of the benthic community, and PRGs developed for RAO 4 are consistent with the SMS for protection of higher trophic level species. Appendix A discusses the SMS ARAR in greater detail.

Under the SMS, sediment cleanup levels (SCLs) may be established on a site-specific basis within an allowable range of contaminant concentrations. The low end of the range is the SCO, and the high end of the range is the cleanup screening level (CSL). The SCL is originally set at the SCO; however, it may be adjusted upward from the SCO based on consideration of whether it is technically possible to achieve the SCO at the applicable point of compliance[39] and whether meeting the SCO will have a net adverse environmental effect on the aquatic environment, natural resources, and habitat. The SCL may not be adjusted upward above the CSL (WAC 173-204-560).

The SCO is the higher of the risk-based levels, PQLs, and natural background. The CSL is the higher of the risk-based levels, PQLs, and regional background. For RAOs 1 and 2, the SCO (lower) risk-based values are based on an estimated lifetime excess risk of less than or equal to 1×10^{-6} for individual carcinogens, less than or equal to 1×10^{-5} for multiple carcinogens or exposure pathways, or HQ less than or equal to 1 for individual contaminants and HI of less than or equal to 1 for multiple contaminants with similar toxic actions. The CSL (higher) risk-based values are based on an estimated lifetime excess risk of less than or equal to $1 \text{ x } 10^{-5}$ for individual carcinogens, and the same as the SCO for multiple carcinogens or exposure pathways, and non-carcinogens.

At the SCO level, natural background values may be used when they are higher than risk-based levels or PQLs. Natural background values have been established for some contaminants in the Puget Sound area.[40] At the CSL level, regional background values may be used when they are higher than risk-based levels or PQLs. Regional background values have not been established for the geographic area that would include EW. Therefore, PRGs based on regional background concentrations are not considered in this FS.

For RAO 3, the SMS contain numerical sediment contaminant concentration criteria for the protection of the benthic community. The SCO (lower) values are concentrations that

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[39] The SMS define "technically possible" as "capable of being designed, constructed and implemented in a reliable and effective manner, regardless of cost." WAC 173-204-505(23). Ecology guidance, provided in SCUM II (Ecology 2017), confirms that this definition includes both the ability to attain, and to reliably and effectively maintain, the natural background cleanup level by stating that upward adjustment of the cleanup level should be based on "whether it is technically possible to achieve and maintain the cleanup level at the applicable point of compliance." [SCUM II 7.2.3.1, page 7-4].

[40] Ecology's methods for determining natural background concentrations were established in agency guidance, but EPA does not consider agency guidance to be an ARAR (Ecology 2017). EPA disagrees with the statistical method used by Ecology to determine natural background concentrations. Use of EPA's preferred statistical method results in lower values for natural background than those produced using Ecology's method. Natural background values determined using EPA's statistical method are used in this FS.

Ecology has determined will have no adverse effects on the benthic community. The CSL (higher) values represent concentrations that Ecology has determined will have minor adverse effects. The SCO for protection of the benthic community (WAC 173-204-562) is referred to as the "SQS" in this document for consistency with previous documents, and these values are equivalent to the marine SQS (WAC 173-204-320). The SQS are applied on a point basis to the biologically active zone of the sediments (i.e., upper 10 cm). Co-located sediment toxicity test results override the numerical criteria for determining compliance with RAO 3. The SCLs for RAO 3 are applied on a point-by-point basis (i.e., without area averaging).

Based on preliminary evaluations, the EW OU cleanup is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2), protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. Modeling, in Appendix A, of the hypothetical maximum remediation scenario at the completion of cleanup implementation and modeling of long-term site-wide concentrations following source control of LDW and EW lateral inputs both predict that surface sediments in the EW OU will not attain all natural background-based PRGs for protection of human health for seafood consumption (RAO 1). Long-term site-wide concentrations are driven primarily by the ongoing contribution of elevated concentrations from diffuse, nonpoint sources of contamination that contribute to regional background concentrations.[41] However, achieving the MTCA/SMS ARARs may nonetheless occur in one of the following two ways:

- Post-remedy monitoring may demonstrate sediment concentrations lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for a Sediment Recovery Zone (SRZ), as provided by the SMS at WAC 173-204-590(3) (see Section 5 of Appendix A).

[41] Source control and sediment cleanup measures are assumed for FS modeling purposes to effectively address discrete sources of contamination, leaving sediment concentrations that are assumed to be "primarily attributable to diffuse sources, such as atmospheric deposition or storm water, not attributable to a specific source or release." WAC 173-204-505(16).

- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or Explanation of Significant Differences (ESD) (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition to these two potential MTCA/SMS ARARs compliance mechanisms, a final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a technical impracticability (TI) waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

Because it is not known whether, or to what extent, the SMS ARARs for total PCBs and dioxins/furans will be achieved in the long term, the selection of which of the two compliance mechanisms described above (either meeting the natural background PRG in a reasonable restoration timeframe, or upwardly adjusting the SCL to regional background and meeting it in a reasonable restoration timeframe) is not identified at this time.

As described in Section 4.1, surface water quality criteria are ARARs for the EW. The water column is affected by the sediment contaminant concentrations, as well as by other factors, including ongoing releases, inflowing water from the Green/Duwamish River system and Elliott Bay, direct discharges to the EW, and atmospheric deposition. The water column cannot practicably be directly remediated, but will be improved by implementation of the selected remedy and by source control actions as discussed in Section 4.2.2. Surface water is a key exposure pathway for consumption of aquatic organisms by humans and wildlife. Following construction, surface water quality data will be compared to these ARAR values to measure progress toward achieving RAOs 1 and 4, and will be evaluated as discussed in Section 4.2.1. Because the WQC are CERCLA ARARs, the quality of EW surface water will have to meet the more stringent of the recommended federal WQC and state WQS for aquatic life and human health (for consumption of organisms only) or be waived at or before completion of CERCLA remedial action.

Water quality improvements are anticipated as a result of sediment remediation and source control. Water quality monitoring will be part of the selected remedy to help measure the efficacy of sediment remediation and source control, and to assess compliance with ARARs. Based on upstream and downstream water quality measurements, none of the remedial alternatives developed and evaluated in this FS are anticipated to meet all surface water quality standards. A surface water quality ARAR waiver could be issued by EPA; potential ARAR waivers are listed in Section 121(d)(4) of CERCLA. The most common waiver is for TI.

4.3.2 Role of RBTCs

The SRI developed site-specific sediment RBTCs (summarized in Section 3.3 of this document) for each of the risk driver COCs. RBTCs for human health were calculated based on risks associated with the direct sediment contact RME scenarios and seafood consumption RME scenarios. RBTCs for fish were calculated based on prey consumption using a calibrated FWM (applicable only to PCBs). For the benthic invertebrate community, RBTCs were set at the SQS and CSL for SMS parameters and were based on site-specific BSAF values for TBT.

Total PCBs, cPAHs, and dioxins/furans are the risk driver COCs for the human seafood consumption pathway. Sediment RBTCs for total PCBs were calculated for the 1×10^{-4} excess cancer risk level and are applied as site-wide average concentrations.[42, 43] As discussed in Section 3.3.4, sediment RBTCs based on the seafood consumption pathway were not calculated for cPAHs because correlations between sediment contaminant concentrations and clam receptor tissue concentrations could not be established.[44] Sediment RBTCs for

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[42] Compliance for remedial actions for RAOs 1, 2, and 4 will be based on site-wide or clamming area UCL95 of post-remediation sediment sampling data.

[43] For the excess cancer risk levels of 1 in 1,000,000 (1×10^{-6}) and 1 in 100,000 (1×10^{-5}) and for the non-cancer HQ of 1, even at a total PCB concentration of 0 µg/kg dw in sediment, the food web model predicted total PCB concentrations in tissue that would result in a risk estimate greater than the risk levels for the RME seafood consumption scenarios because of the contribution of total PCBs from water alone, even at concentrations similar to those in upstream Green River water (i.e., 0.3 ng/L). Therefore, sediment RBTCs for these risk levels were represented as "< 1" (see Table 3-13).

[44] Data show little relationship between clams and sediment for cPAHs, and clam concentrations may be more related to the surface water pathway.

dioxins/furans were calculated for the 1 x 10^{-4}, 1 x 10^{-5}, and 1 x 10^{-6} excess cancer risk level and for an HQ of 1 and are applied as site-wide average concentrations.

Arsenic was identified as human health risk driver COCs for the direct sediment contact pathway. Sediment RBTCs for this hazardous substance was presented in Table 3-10 for the two direct sediment contact RME scenarios (i.e., netfishing on a site-wide basis and tribal clamming in clamming areas). These sediment RBTCs are average concentrations applied to the spatial area over which exposure would reasonably be expected.

A range of total PCB sediment RBTCs was calculated to protect fish depending on the tissue RBTC (based on toxicity reference values and associated uncertainties) and species. These RBTCs are applied as site-wide average concentrations. Appendix A describes the method used to establish a sediment PRG for each of two fish species.

4.3.3 Role of Background Concentrations

Both CERCLA and the SMS (MTCA) consider background hazardous substance concentrations when formulating PRGs and cleanup levels. Both recognize that setting numerical cleanup goals at levels below background is impractical (because of the certainty of recontamination to at least the background concentration). The SMS define natural background as the concentrations of hazardous substances that are consistently present in an environment that have not been influenced by localized human activities. Thus, under the SMS, a natural background concentration can be defined for man-made compounds even though they may not occur naturally (e.g., PCBs deposited by atmospheric deposition into an alpine lake). 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).

SMS cleanup levels cannot be set at concentrations below natural background (WAC 173-204-560). Similarly, CERCLA guidance states that natural background concentrations establish a limit below which a lower cleanup level cannot be achieved (EPA 2005).

Both cleanup programs also recognize that natural and man-made hazardous substance concentrations can occur at a site in excess of natural background concentrations, not as a result of controllable local site-related releases but caused by human activities in areas removed from the site and natural processes that transport the contaminants to the site (e.g., atmospheric uptake, transport, and deposition). CERCLA defines “anthropogenic background” 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). The SMS define the term “regional background” as concentrations in an Ecology-defined geographic area that are attributable to “diffuse sources, such as atmospheric deposition or storm water, not attributable to a specific source or release” (WAC 173-204-505 (16)). CERCLA generally does not require cleanup to concentrations below anthropogenic background concentrations; the SMS allow upward adjustment of cleanup levels to regional background. More stringent state standards must be met by a CERCLA remedial action or waived by EPA at or before completion of the remedial action. The adjustment of cleanup standards for total PCBs and dioxins/furans from natural background to regional background is discussed in Appendix A.

4.3.3.1 Natural Background in Sediment

This section presents estimates of natural background concentrations for total PCBs, cPAHs, arsenic, and dioxins/furans in sediment.[45] To characterize natural background, marine sediment data were compiled from areas within Puget Sound that have not been influenced by localized human activities. These data represent non-urban, non-localized concentrations that exist as a result of natural processes and/or the large-scale distribution of these hazardous substances from anthropogenic sources in a large marine receiving body.

The DMMP (comprised of USACE, EPA, Ecology, and DNR) collected sediment data throughout Puget Sound and the Strait of Juan de Fuca in the summer of 2008 and documented the results in a report called *Final Data Report: OSV Bold Summer 2008 Survey* (DMMP 2009). Data were collected from 70 sampling locations throughout Puget Sound, as well as from the area around the San Juan Islands and the Strait of Juan de Fuca. Locations for each target sampling station are displayed in Figure 4-1. A subset of these sample locations

[45] EPA will set cleanup levels and remediation goals in the ROD.

(N = 20) consisted of locations in four reference areas (Carr Inlet, Samish Bay, Holmes Harbor, and Dabob Bay) established by Ecology. In each of these reference areas, five target sediment sampling locations were located based on a stratified random sampling design. The remaining 50 sample locations were spread throughout Puget Sound and the straits of Georgia and Juan de Fuca and were intended to represent areas outside the influence of urban bays and known point sources. At five stations, a duplicate sample (or field split) was collected for quality assurance purposes. Samples were analyzed for the full suite of DMMP contaminants, including SVOCs, dioxins/furans, PCB Aroclors, PCB congeners, organochlorine pesticides, and trace metals, as well as for sediment conventionals (e.g., TOC, grain size, percent solids).

The statistical methods used to develop background concentrations are important for consistency with other regional sites and for measuring compliance. EPA calculates natural background concentrations based on the UCL95 from the background population, as was also presented in the LDW FS (AECOM 2012). Ecology uses an alternate method for determining natural background concentrations[46] which was established in Ecology's Sediment Cleanup User's Manual (SCUM) II (Ecology 2017). SCUM II is not an ARAR under CERCLA, although portions of SCUM II may be evaluated as "to be considered" criteria. EPA disagrees with the statistical method used by Ecology to determine natural background concentrations for establishing PRGs in compliance with CERCLA. Use of EPA's preferred statistical method results in lower values for natural background than those produced using Ecology's method. Natural background values determined using EPA's statistical method are used in this FS. Summary statistics for natural background calculations are presented in Table 4-2 for each of the four human health risk driver COCs.

Natural Background for Arsenic in Sediment

Arsenic was detected in all of the samples from the OSV *Bold* Survey (Table 4-2). Concentrations ranged from 1.1 to 21 mg/kg dw, with a mean concentration of 6.5 mg/kg dw, a 90th percentile of 11 mg/kg dw. Calculating the UCL95 of the OSV *Bold* Survey dataset results in a natural background value of 7 mg/kg dw.

[46] For informational and comparison purposes, Appendix A presents the natural background values calculated by Ecology in SCUM II.

Natural Background for Total PCBs in Sediment

Total PCBs as Aroclors were below reporting limits in the majority of sediment samples from the OSV *Bold* Survey (Table 4-2). The PCB congener method, with its lower reporting limits, produced a detection frequency of 100%, based on quantifying at least one PCB congener in each sample. Total PCBs in each sample were calculated by summing the concentrations of all detected PCB congeners, consistent with the protocol in the SMS for reporting total PCBs by summing the concentrations of all detected PCB Aroclors. Using the congener results, total PCB concentrations ranged from 0.01 to 10.6 μg/kg dw, with a mean of 1.2 μg/kg dw a 90th percentile of 2.7 μg/kg dw. Calculating the UCL95 of the OSV *Bold* Survey dataset results in a natural background value of 2 μg/kg dw.

Table 4-2

Summary of Arsenic, Total PCB, cPAH, and Dioxin/Furan Sediment Data for Natural Background Concentrations

Human Health Risk Driver COC	Detection Frequency	Minimum	Maximum	Mean	Median	90th Percentile	EPA-calculated UCL95 (rounded value)[b]
Arsenic (mg/kg dw)	70/70	1.1	21	6.5	6.0	11	7
Total PCBs as Congeners (µg/kg dw)[a]	70/70	0.01	10.6	1.2	0.7	2.7	2
cPAHs (µg TEQ/kg dw)	61/70	1.3	57.7	7.1	4.5	15	9
Dioxins/furans (ng TEQ/kg dw)	70/70	0.23	11.6	1.4	1.0	2.2	2

Notes:
1. The summary statistics above are for the dataset collected throughout Puget Sound by DMMP in 2008 and referred to as the OSV *Bold* Survey (*Bold* dataset; DMMP 2009).
2. Total PCBs were calculated by summing the concentrations of detected PCB congeners.
3. Total cPAHs were calculated by summing the concentrations of all detected cPAH compounds multiplied by their respective PEFs, along with half the reporting limits) of any undetected cPAH compounds multiplied by their respective PEFs.
4. The dioxin TEQ (relative to that of 2,3,7,8-tetrachlorodibenzo-p-dioxin) was calculated by summing the concentrations of detected polychlorinated dibenzo-p-dioxin or furan congeners multiplied by their respective TEFs, along with half the reporting limits of undetected polychlorinated dibenzo-p-dioxin or furan congeners multiplied by their respective TEFs.

a. Only PCB congener data from the OSV *Bold* Survey (DMMP 2009) study were used, as there were few detected values in the Aroclor data.
b. EPA calculated natural background based on the UCL95 using the OSV *Bold* Survey (DMMP 2009) dataset, as presented in the LDW ROD (EPA 2014).

µg – micrograms
ARAR – applicable or relevant and appropriate requirement
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DMMP – Dredged Material Management Program
dw – dry weight
Ecology – Washington State Department of Ecology
EPA – U.S. Environmental Protection Agency
kg – kilogram
mg – milligram
ng – nanogram
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
TEF – toxic equivalency factor
TEQ – toxic equivalent
UCL95 – 95% upper confidence limit on the mean

Natural Background for cPAHs in Sediment

The detection frequency for cPAHs in the OSV *Bold* Survey was 87%, based on quantifying at least one cPAH compound in each sample (Table 4-2). Total cPAHs in each sample were calculated by summing the concentrations of all detected cPAH compounds multiplied by their respective benzo(a)pyrene potency equivalency factors (PEFs), along with half the reporting limits of any undetected cPAH compounds multiplied by their respective PEFs. Concentrations ranged from 1.3 to 57.7 μg TEQ/kg dw, with a mean concentration of 7.1 μg TEQ/kg dw, a 90th percentile of 15 μg TEQ/kg dw. Using the UCL95 of the OSV *Bold* Survey dataset results in a natural background value of 9 μg TEQ/kg dw.

Natural Background for Dioxins/Furans in Sediment

The detection frequency for dioxins/furans in the OSV *Bold* Survey was 100%, based on quantifying at least one congener in each sample (Table 4-2). The total TEQ of dioxins/furans (relative to that of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin) in each sample was calculated by summing the concentrations of certain detected polychlorinated dibenzo-*p*-dioxin or furan congeners multiplied by their respective toxic equivalency factors (TEFs), along with half the reporting limits of undetected polychlorinated dibenzo-*p*-dioxin or furan congeners multiplied by their respective TEFs. Concentrations ranged from 0.23 to 11.6 ng TEQ/kg dw, with a mean of 1.4 ng TEQ/kg dw (Table 4-2), a 90th percentile of 2.2 ng TEQ/kg dw. Using the UCL95 of the OSV *Bold* Survey dataset results in a natural background value of 2 ng TEQ/kg dw.

4.3.3.2 Regional Background in Sediment

Appendix A discusses the justification under SMS for the adjustment of cleanup levels for PCBs and dioxins/furans based on the considerations in WAC 173-204-560(4). Because regional background has not been established for the EW, the PRGs for RAO 1 (based on complying with SMS as an ARAR) are set at the SCO for both PCBs and dioxins/furans (based on natural background).

4.3.4 Role of Practical Quantitation Limits

Both CERCLA and MTCA/SMS allow consideration of PQLs when formulating PRGs to address circumstances in which a concentration determined to be protective cannot be reliably detected using state-of-the-art analytical instruments and methods. For example, if an RBTC is below the concentration at which a contaminant can be reliably quantified, then the PRG for that contaminant may default to the analytical PQL. MTCA defines the PQL 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 (WAC 173-340-200).*

In simpler terms, the PQL is the minimum concentration for an analyte that can be reported with a high degree of certainty.

Tables 4-3 and 4-4 list the risk driver-specific PQLs developed for the SRI sediment sampling programs and documented in the associated quality assurance project plans. These PQLs represent the lowest values that can be reliably quantified when the sample matrix (in this case, sediment) is free of interfering compounds that can reduce sensitivity and raise reporting limits. Also, these tables present the range of actual sample PQLs reported by the laboratories for the data in the SRI database. These results reflect the range of what the laboratories were able to achieve given the composition of, and matrix complexity associated with, EW OU sediment samples.

Analytical quantitation limits are generally not expected to exceed RBTCs, SQS, or natural background concentrations for samples of low matrix complexity. However, empirical evidence from the SRI suggests that, on a case-by-case basis, matrix interferences have the potential to preclude quantification to concentrations below the PRGs (and ultimately the cleanup levels and standards) established for cleanup of EW OU sediments.

Table 4-3
Preliminary Remediation Goals for Total PCBs, Arsenic, cPAHs, and Dioxins/Furans in Sediment for Human Health and Ecological Risk Driver COCs

Analyte	Practical Quantitation Limits		Natural Background	Risk-based Threshold Concentration[a]				Preliminary Remediation Goals		Spatial Scale for PRG Application[d]
	SRI QAPP RLs	Range of RLs from Undetected Values	EPA's Method UCL95	RAO 1: Human Seafood Consumption	RAO 2: Human Direct Contact	RAO 3: Benthic Organisms[b]	RAO 4: Ecological[c]	Value	Basis	
Total PCBs (µg/kg dw)	4[e]	3.9 – 35[f]	2[g]	2 – 250[h]	NA	NA	39 – 458[i] 100 – >470[i]	2(RAO 1) 250, 370 (RAO 4)[j]	Natural Background (RAO 1); RBTC (RAO 4)	Site-wide
				NA	NA	12/65[k]	NA	12 (mg/kg OC) (RAO 3)	RBTC	Point
Arsenic (mg/kg dw)	0.5	5 – 20	7	NA	3.7	NA	NA	7(RAO 2)	Natural Background	Site-wide
				NA	1.3	NA	NA	7(RAO 2)	Natural Background	Clamming Areas
				NA	NA	57/93[k]	NA	57 (RAO 3)	RBTC	Point
cPAH (µg TEQ/kg dw)	5.9 – 9.5	20 – 48[l]	9	NA[n]	NA	NA[m]	NA	NA	NA	NA
Dioxins/furans (ng TEQ/kg dw)	0.5[o]	NA	2	0.18 – 0.94[p]	NA	NA	NA	2(RAO 1)	Natural Background	Site-wide

Notes:
a. RBTCs developed in the Final SRI (Windward and Anchor QEA 2014).
b. Sediment RBTCs are also included as the SQS and CSL for the remaining 29 risk driver COCs and TBT for the benthic invertebrate community (see Table 4-4).
c. RAO 4 includes RBTCs (based on two LOAEL TRVs; see Section 3.3.1) for protection of English sole and brown rockfish for PCBs.
d. The spatial scale of site-wide exposure is RAO-specific (e.g., seafood consumption for RAO 1 and netfishing for RAO 2 is site-wide, while tribal clamming for RAO 2 is intertidal clamming areas).
e. PCB RLs (as Aroclors) reported; RLs for individual PCB congeners are much lower (0.5 to 1 ng/kg dw).
f. Range of RLs for undetected values were queried from the SRI database and represent RLs for undetected total PCBs. For samples in which none of the individual Aroclors are detected, the total PCB concentration value is represented as the highest RL of an individual Aroclor, and assigned a U-qualifier, indicating no detected concentrations. 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.
g. Total PCB value based on the sum of detected PCB congeners.
h. The RBTC is less than 1 µg/kg dw at excess cancer risk levels of 10^{-5} and 10^{-6} and for a Hazard Quotient equal to 1; the RBTC range of 2 to 250 µg/kg dw for the three RME seafood consumption scenarios is at the 10^{-4} excess cancer risk level.
i. Values represent the RBTCs for brown rockfish (39 – 458 µg/kg dw) and English sole (100 – >470 µg/kg dw). The value >470 µg/kg dw indicates that even under current conditions in the EW OU (based on an existing sediment SWAC of 470 µg/kg dw), average tissue concentrations are estimated to be less than the upper bound tissue RBTC.
j. As described in Appendix A, the sediment PRG is based on the mean of the RBTC values for each fish receptor. Two PRGs have been established based on brown rockfish (250 µg/kg dw) and English sole (370 µg/kg dw).
k. Total PCB concentration units are mg/kg OC and the two values are SQS/CSL. Arsenic concentration units are mg/kg dw and the two values are SQS/CSL.
l. RLs are based on non-detect samples for individual cPAH compounds with units of µg/kg dw. If none of the individual cPAH compounds were detected, then half the RL was multiplied by the PEF for each compound to calculate the cPAH TEQ RL value.
m. Low- and high-molecular weight PAHs are addressed by the SMS. Criteria are set for both groupings and for individual PAH compounds (see Table 4-4).
n. cPAH PRGs are undefined for the human health seafood consumption pathway (RAO 1). Seafood consumption excess cancer risks for cPAHs were largely attributable to the consumption of clams. There is no consistent relationship, based on site data, relating cPAH concentrations in sediment to concentrations in clam tissue (see Section 8 of SRI; Windward and Anchor QEA 2014). Section 8 of the FS discusses the potential need for future investigations of the sediment/tissue relationship for cPAHs.
o. Dioxins/furans RLs are based on the reporting limits for the individual compounds with units of ng/kg dw.
p. RBTC of 0.18 and 0.94 calculated for adult tribal and child tribal RME scenarios at risk level of 10^{-6} excess cancer risk threshold, respectively.

µg/kg – micrograms per kilogram
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSL – cleanup screening level
dw – dry weight
ng/kg – nanograms per kilogram
OC – organic carbon-normalized
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
PRG – preliminary remediation goal
RL – reporting limit
RME – reasonable maximum exposure
SCO – sediment cleanup objective
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard

Ecology – Washington State Department of Ecology
EPA – U.S. Environmental Protection Agency
FS – feasibility study
LOEAL – lowest-observed-adverse-effect level
mg/kg – milligrams per kilogram
NA – not applicable
QAPP – quality assurance project plan
RAO – remedial action objective
RBTC – risk-based threshold concentration
SRI – Supplemental Remedial Investigation
SWAC – spatially-weighted average concentration
TBT – tributyltin
TEQ – toxic equivalent
TRV – toxicity reference value
UCL95 –- 95% upper confidence limit on the mean

Table 4-4

Preliminary Remediation Goals for Sediment for Benthic Risk Driver COCs

Contaminant	Practical Quantitation Limit (mg/kg dw)			Risk-Based Threshold Concentrations (RAO 3): Sediment Management Standards (mg/kg dw[a] or mg/kg OC[b]) and TBT[c]		Preliminary Remediation Goal[d]			Detection Frequency		Frequency of Detected concentrations above SQS	
	EPA Method	SRI QAPP RLs	Range of RLs from Undetected Values	Sediment Quality Standard (SQS)	Cleanup Screening Level (CSL)	Value	Basis	Spatial Scale of PRG Application	No. of Samples[e]	%	No. of Samples[f]	%
Metals												
Arsenic	EPA 6010B	0.5	6-20[g]	57[a]	93[a]	57[a]	SQS	Point	162/231	70	2/231	0.9
Cadmium	EPA 6010B	0.2	0.2-1.0	5.1[a]	6.7[a]	5.1[a]	SQS		155/231	67	2/231	0.9
Mercury	**EPA 7471A**	**0.05**	**0.04-0.07**	**0.41[a]**	**0.59[a]**	**0.41[a]**	SQS		**233/239**	**98**	**46/239**	**19**
Zinc	EPA 6010B	4.0	NA	410[a]	960[a]	410[a]	SQS		231/231	100	5/231	2.2
PAHs												
2-Methylnaphthalene	EPA 8270D	0.02	0.019 -0.190	38[b]	64[b]	38[b]	SQS	Point	87/240	36	1/240	0.4
Anthracene	EPA 8270D	0.02	**0.019-0.062**	**220[b]**	**1,200[b]**	**220[b]**	SQS		**209/240**	**87**	1/240	0.4
Acenaphthene	EPA 8270D	0.02	**0.019-0.12**	**16[b]**	**57[b]**	**16[b]**	SQS		**126/240**	**53**	**16/240**	**6.7**
Benzo(a)anthracene	EPA 8270D	0.02	0.020-0.061	110[b]	270[b]	110[b]	SQS		226/240	94	7/240	2.9
Benzo(a)pyrene	EPA 8270D	0.02	0.019-0.061	99[b]	210[b]	99[b]	SQS		225/240	94	7/240	2.9
Benzo(g,h,i)perylene	EPA 8270D	0.02	0.019-0.061	31[b]	78[b]	31[b]	SQS		212/240	88	4/240	1.7
Total benzofluoranthenes[h]	EPA 8270D	0.02	0.019-0.061	230[b]	450[b]	230[b]	SQS		228/240	95	7/240	2.9
Chrysene	EPA 8270D	0.02	0.019-0.061	110[b]	360[b]	110[b]	SQS		230/240	96	8/240	3.3
Dibenzo(a,h)anthracene	EPA 8270D-SIM	0.0063	0.019-0.12	12[b]	33[b]	12[b]	SQS		156/240	65	4/240	1.7
Dibenzofuran	EPA 8270D	0.02	0.019-0.190	15[b]	5[b]	15[b]	SQS		107/240	45	8/240	3.3
Fluoranthene	EPA 8270D	0.02	**0.02-0.061**	**160[b]**	**1,200[b]**	**160[b]**	SQS		**233/240**	**97**	**14/240**	**5.8**
Fluorene	EPA 8270D	0.02	**0.019-0.120**	**23[b]**	**79[b]**	**23[b]**	SQS		**144/240**	**60**	**12/240**	**5.0**
Indeno(1,2,3-cd)pyrene	EPA 8270D	0.02	0.019-0.062	34[b]	88[b]	34[b]	SQS		210/240	88	6/240	2.5
Phenanthrene	EPA 8270D	0.02	**0.019-0.061**	**100[b]**	**480[b]**	**100[b]**	SQS		**230/240**	**96**	**15/240**	**6.3**
Pyrene	EPA 8270D	0.02	0.020-0.061	1,000[b]	1,400[b]	1,000[b]	SQS		235/240	98	1/240	0.4
Total HPAHs[i]	EPA 8270D	0.02	0.020	960[b]	5,300[b]	960[b]	SQS		237/240	99	9/240	3.8
Total LPAHs[j]	EPA 8270D	0.02	0.019-0.061	370[b]	780[b]	370[b]	SQS		230/240	96	8/240	3.3
Phthalates												
BEHP	EPA 8270D	0.02	0.020-1.40	47[b]	78[b]	47[b]	SQS	Point	207/231	90	9/231	3.9
BBP	EPA 8270D-SIM	0.0067	0.014-0.190[g]	4.9[b]	64[b]	4.9[b]	SQS		101/231	44	9/231	3.9
Di-n-butyl phthalate	EPA 8270D	0.02	0.019-0.190	220[b]	1,700[b]	220[b]	SQS		32/231	14	1/231	0.4

Table 4-4
Preliminary Remediation Goals for Sediment for Benthic Risk Driver COCs

Contaminant	Practical Quantitation Limit (mg/kg dw)			Risk-Based Threshold Concentrations (RAO 3): Sediment Management Standards (mg/kg dw[a] or mg/kg OC[b]) and TBT[c]		Preliminary Remediation Goal[d]			Detection Frequency		Frequency of Detected concentrations above SQS	
	EPA Method	SRI QAPP RLs	Range of RLs from Undetected Values	Sediment Quality Standard (SQS)	Cleanup Screening Level (CSL)	Value	Basis	Spatial Scale of PRG Application	No. of Samples[e]	%	No. of Samples[f]	%
Other SVOCs												
1,4-Dichlorobenzene	EPA 8270D-SIM	0.0067	**0.0009-0.020**	**3.1[b]**	**9.0[b]**	**3.1[b]**	SQS	Point	**146/231**	**63**	**29/231**	**13**
2,4-Dimethylphenol	EPA 8270D-SIM	0.0067	0.019-0.500[g]	0.029[b]	0.029[b]	0.029[b]	SQS		14/231	6.1	1/231	0.4
n-Nitrosodiphenylamine	EPA 8270D-SIM	0.0067	0.0059-0.190	11[b]	11[b]	11[b]	SQS		2/231	0.90	1/231	0.4
Phenol	EPA 8270D-SIM	0.0067	0.019-0.190[g]	0.42[a]	1.2[a]	0.42[a]	SQS		94/231	41	5/231	2.2
PCBs												
Total PCBs	EPA 8082	**0.5**	0.51-3.4	**12[b]**	**65[b]**	**12[b]**	SQS	Point	**227/240**	**95**	**157/240**	**66**
Tributyltin												
Tributyltin	Krone 1989	**0.004**	**0.0034-0.0037**	**7.5[b,c]**		**7.5[b]**	RBTC	Point	**60/67**	**90**	**10/67**	**0.2**

Bold – indicates the contaminant for which 5% or more of the surface sediment samples had detected concentrations above the SQS.

a. Units are mg/kg dw for these contaminants.
b. Units are mg/kg OC for these contaminants
c. An organic carbon normalized sediment RBTC was calculated in the EW SRI (Windward and Anchor QEA 2014). The frequency of detected concentrations above the RBTC is shown.
d. PRGs are considered on the basis of a point concentration or toxicity test pass.
e. Represents the number of detects per total number of samples.
f. Represents the number of detects > SQS per total number of samples. If any individual sample had a TOC content > 4% or < 0.5% and the dry-weight concentration was > LAET, the concentration was considered to be > SQS.
g. RLs elevated above the QAPP RLs due to analytical dilution and matrix interferences.
h. Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.
i. Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.
j. Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
dw – dry weight
EPA – U.S. Environmental Protection Agency
EW – East Waterway
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
LAET – lowest-apparent-effect threshold
mg/kg – milligrams per kilogram
NA – not applicable
OC – organic carbon-normalized
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
PRG – preliminary remediation goal
QAPP – quality assurance project plan
RAO – remedial action objective
RBTC – risk-based threshold concentration
RL – reporting limit
SQS – sediment quality standard
SRI – Supplemental Remedial Investigation
SVOC – semivolatile organic compound
TBT – tributylin
TOC – total organic carbon

4.4 Preliminary Remediation Goals

When selecting PRG(s) for each RAO, the higher value of the RAO RBTC, background, or PQL is selected. Regional background concentrations have not been established for the EW but Appendix A evaluates the criteria for adjustment of the cleanup level above natural background-based cleanup levels for PCBs and dioxins/furans. PQLs were not found to influence selection of the PRGs (i.e., all PRGs are above SRI PQLs). Following completion of the final FS, upward adjustment of the cleanup level may occur once a regional background concentration is determined for the EW area.[47] The RAOs and PRGs are considered in selecting the RALs in Section 6 of the FS. Section 9 compares estimated concentrations of risk driver COCs following sediment remediation to PRGs as one measure of the effectiveness of the remedial alternatives.

Tables 4-3 and 4-4 summarize the analysis and selection of sediment PRGs for the risk driver COCs. Table 4-3 focuses on the four human health risk driver COCs and the fish risk driver COC, and is subdivided to address the various spatial applications of the PRGs for each RAO. Table 4-4 contains the PRG analysis for the risk driver COCs for RAO 3. PRGs were developed only for risk driver COCs identified in the SRI. The potential for risk reduction for the other COCs following remedial action is evaluated in Section 9.

The PRGs are applied on either a point basis or an average basis over a given exposure area depending on the COC, exposure pathway, and receptor of concern. PRGs for RAOs 1, 2, and 4 are applied on an area-wide average basis that requires a sediment SWAC over the applicable exposure area to be below the PRG. SWACs are calculated following sediment remediation to evaluate and compare remedial alternatives (see Sections 9 and 10); compliance

[47] SCUM II (Ecology 2017) states: "Ecology may consider whether the cleanup level should be adjusted upwards according to the process detailed in Chapter 7, Section 7.2.3. An example of when this may be appropriate is where the cleanup level was established below regional background, but Ecology has since established or approved regional background for the geographic area where the site is located. In this case, Ecology may determine that regional background represents the concentration in sediment that is technically possible to maintain, due to ongoing sources that are not under the authority or responsibility of the PLP. Therefore, Ecology could allow upwards adjustment of the sediment cleanup level to the CSL if regional background has been established as the CSL."

for remedial actions for RAOs 1, 2, and 4 will be based on the UCL95 of post-remediation sampling data. RAO 3 is applied on a point basis for protection of benthic organisms.

For RAO 1, the numerical PRGs for total PCBs and dioxins/furans are set to natural background because the sediment RBTCs[48] for the RME seafood consumption scenarios are below natural background. The natural background concentration is estimated using the EPA methodology. cPAH PRGs were not identified for the human health seafood consumption pathway (RAO 1). Excess cancer risks for cPAHs were largely attributable to the consumption of clams. Based on data collected during the SRI, there is not a significant relationship between cPAH concentrations in sediment and concentrations in clam tissue (Section 8 of the SRI; Windward and Anchor QEA 2014). However, the development and evaluation of remedial alternatives in the latter sections of the FS discuss the potential need for future investigations of the sediment/clam tissue relationships for cPAHs.

For RAO 2, the PRG is based on a comparison between the sediment RBTC (1×10^{-6} excess cancer risk threshold) and background (whichever is higher). RBTCs were developed for two exposure scenarios: netfishing and tribal clamming direct contact (which includes both dermal contact and incidental ingestion) with sediment. The PRG is applied on a spatially-weighted average basis over a given exposure area (e.g., site-wide for the netfishing PRG and over clamming areas for the tribal clamming PRG). The arsenic PRG is based on natural background because the RBTCs at 1×10^{-6} excess cancer risk threshold are below natural background.

For RAO 3, the SMS numerical criteria for the protection of benthic organisms apply on a point basis (Table 4-4). As noted in Section 4.3.1, WAC 173-204-570(4) specifies that the site-specific cleanup standards shall be as close as practicable to the SCO, but in no case shall exceed the minimum cleanup level (the CSL). For this reason, the PRGs for RAO 3 in this FS

[48] For PCBs, sediment RBTCs were calculated only for the 1×10^{-4} excess cancer risk threshold. The contribution of PCBs in water alone (even at concentrations similar to those in Green River) was high enough to result in seafood consumption risks for Adult and Child Tribal RME and Asian and Pacific Islander RME scenarios exceeding the 1×10^{-6} and 1×10^{-5} excess cancer risk thresholds even in the absence of any contribution from sediment (Table 3-13). For dioxins/furans, sediment RBTCs were below natural background for all RME scenarios for the 1×10^{-6} excess cancer risk threshold.

are set to the SQS (same as the benthic SCO). However, where co-located toxicity test data are available, sediment toxicity results override the numerical criteria for RAO 3. A PRG for TBT is also established for RAO 3 based on the sediment RBTC (Table 4-4).

For RAO 4, PRGs for total PCBs for the protection of fish are based on RBTCs (HQ less than 1). Appendix A details the development of each fish PRG based on available RBTCs. The selected PRGs are shown in Table 4-3).

Predicted post-remedy HQs and risks calculated using the EW food web model-predicted tissue concentrations are presented in Section 9. EPA will establish target tissue concentrations to measure progress toward achieving RAOs 1 and 4 in the ROD. Target tissue concentrations are not cleanup levels; they will be used for informational purposes and to assess ongoing risks to people and ecological receptors.

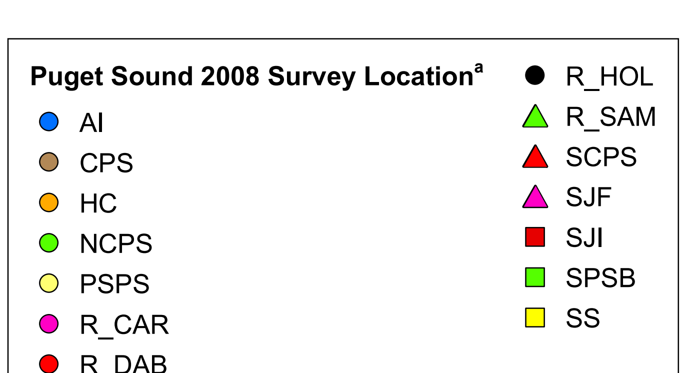

Figure 4-1
Locations of Surface Sediment Data Available for Arsenic, PCBs, cPAHs, and Dioxins and Furans from the Puget Sound 2008 Survey for Natural Background Consideration
Feasibility Study
East Waterway Study Area

[a] Additional details on these sample locations are in the OSV Bold Summer 2008 Survey Data Report (DMMP 2009).

5 PREDICTIVE EVALUATION METHODOLOGY FOR SITE PERFORMANCE OVER TIME

This section provides an overview of the information and methodology used to predict site performance over time based on remedial alternatives. Remedial alternatives are described in Section 8, and the results of the evaluations described in this section are provided in Section 9. Sediment transport in the EW was evaluated using site-specific empirical data and modeling and presented in the EW STER (Anchor QEA and Coast & Harbor Engineering 2012). The results of the STER were used to develop the Physical Processes CSM (hydrodynamics and sediment transport) provided in the EW SRI (Windward and Anchor QEA 2014). Additional analyses conducted following approval of the EW SRI resulted in modifications to the Physical Processes CSM, as described in the SRI, related to variable net sedimentation rates within the EW and estimates of the site-wide net sedimentation rate for the EW. These additional analyses are documented in Appendix J. The understanding of sediment transport in the EW developed through the STER, SRI, and these additional analyses are used in this FS to inform development of remedial alternatives and to evaluate site performance over time after remediation.

Section 5.1 provides a summary of information from the STER, SRI, and additional analyses conducted following approval of the SRI, that are pertinent to the evaluations described in this section. This information includes a general overview of sediment transport within the EW, detailed information on solids loads to the EW, mass balance of solids within the EW, net sedimentation rates in the EW, and erosion potential of sediments within the EW due to currents and vessel movements. In-depth discussion of the additional analyses conducted after publication of the Final SRI are provided in Section 2 of Appendix J.

Sections 5.2 through 5.5 describe the purpose for and methodology used to evaluate site performance over time in the EW. The site performance evaluation is divided up into separate assessments as follows:

- Post-construction Sediment Bed Replacement Values and Dredge Residuals (Section 5.2)
- Site-wide Evaluation of Site Performance Over Time (Section 5.3)
- Recontamination Potential Evaluation (Section 5.4)
- Point Mixing Model for Evaluation of RAO 3 (Section 5.5)

A summary outlining sources of uncertainty in this evaluation is provided in Section 5.6. The mathematical basis for the analyses summarized in this section and how uncertainties influence the results of the site performance evaluations are provided in Appendix J.

5.1 Overview of Sediment Transport in the East Waterway

This section provides an overview of sediment transport processes in the EW, as outlined in the Physical Processes CSM developed as part of the SRI (Windward and Anchor QEA 2014) and further refined in additional analysis conducted after formal approval of the SRI.

Sediment sources to the EW include the upstream sources (Green River, LDW bed and bank sediments, and LDW laterals), downstream sources (Elliott Bay), and lateral sources that discharge within the EW. Geochronology cores were collected in the EW to evaluate net sedimentation rates (Anchor QEA and Coast & Harbor Engineering 2012). Cores were placed in areas that had not been recently dredged[49] (see Figure 2-22), and in areas representative of different hydrodynamic regimes (Anchor QEA 2009). Cores were not collected in the Deep Main Body Reach between Stations 2800 and 5000 because this area had been recently dredged. Figure 5-1 shows the locations of each of the 22 geochronology cores attempted, the 18 cores recovered, and the 4 cores that could not be recovered.

The evaluation of the 18 recovered geochronology cores (see Figure 5-1 herein, and SRI Maps 3-11a and 3-11b; Windward and Anchor QEA 2014) suggests that the majority of the Shallow and Deep Main Body Reaches (between Stations 2800 and 6800) and the interior of Slip 27 (Figure 5-1) are net depositional. Net sedimentation rates measured for recoverable cores in these areas range from 0.1 to greater than 4.2 cm/yr based on lead-210 (Pb-210) and cesium-137 (Cs-137) data. There was one core (GC-17) in the Shallow Main Body Reach at the Olympic Tug and Barge berth that may have no recovery due to sands and gravels on the seabed in that location. This result suggests that the area around GC-17 has little to no net deposition due to the influence of vessel operations in that area.

[49] Dredged areas within the EW were expected to have unreadable data for the Cs-137 peak due to the depth of sediment below mudline removed during dredging actions likely removed the Cs-137 peak.

Cores recovered and evaluated in the Deep Main Body Reach between Stations 0 and 2800 suggest that this area is net depositional but influenced by localized episodic mixing and/or erosion events due to propwash from vessel operations. Recovered and evaluated cores in this area did not have a clear Cs-137 peak, which implies that mixing occurred in the past or could be occurring in this area due to vessel operations (propwash). Evaluation of Pb-210 data in these cores did provide an estimate for net sedimentation rates in these areas averaging approximately 0.5 cm/yr. There was one core (GC-04) in the Deep Main Body Reach along the T-18 berth that had no recovery due to sands and gravels on the seabed in that location. As with the area adjacent to the Olympic Tug and Barge berth, this result suggests that the area around GC-04 may have no net deposition due to the influence of vessel operations in that area. Sediment in underpier areas is also expected to have deposition of sediments from upstream and lateral sources and be subject to periodic erosion and resuspension due to impacts from propwash and bow and stern thrusters.

Since geochronology cores were not retrieved in the Sill and Junction Reaches due to presence of consolidated sand and gravel surface sediments, the Sill and Junction Reaches may not be net depositional in the areas where geochronological cores were attempted. Results of the sediment transport modeling (QEA 2008) completed for the LDW FS (AECOM 2012) and modeling results from the PTM for lateral sources within the EW (Anchor QEA and Coast & Harbor Engineering 2012) completed for the SRI/FS suggest that 99% of the incoming suspended sediment to the EW is from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral inputs), and less than 0.3% is from lateral inputs directly discharging to the EW itself. The sediment inputs into the EW from Elliott Bay are assumed to be small relative to upstream and EW lateral source inputs based on existing studies of sediment transport in Elliott Bay and comparison of total suspended solids (TSS) in Elliott Bay and the LDW (see Section 3.1 of the EW SRI; Windward and Anchor QEA 2014).[50] Therefore, sediment loads from Elliott Bay were not included in the analysis.

Comparing modeled estimates of sediment loads and average values of net sedimentation rates in the EW (measured from recovered geochronology cores), between 25% and 60% of

[50] Therefore, sediment inputs to the EW from Elliott Bay were not considered for the modeling efforts; see Sections 5.3 and 5.4.

the incoming suspended sediment is estimated to deposit in the EW, and between 40% and 75% of the incoming suspended sediments is estimated to leave the EW, most likely moving out into Elliott Bay and other locations in Puget Sound (Section 3.4 in the EW SRI; Windward and Anchor QEA 2014). Initial mass deposition patterns within the EW from local lateral sources (evaluated through the PTM discussed in Appendix B, Part 1) show that the majority of initial deposition occurs close to the outfall locations, with relatively little deposition occurring in the deeper areas of the EW.

Riverine and tidal currents in the EW are not expected to cause significant erosion of in situ bed sediments, as the maximum predicted bed shear stress for a 100-year high-flow event is modeled to be less than the critical shear stress[51] of the bed sediments (estimated from site-specific SEDflume data). Modeled bed shear stress due to vessel operations suggests that bed sediments in the Deep Main Body Reach, the Shallow Main Body Reach, and the Junction Reach are subject to episodic erosion and resuspension of bed sediments due to propwash activity.

5.1.1 Sources of Solids Input to the East Waterway

Sediment sources to the EW quantified for the purposes of the FS include upstream sources (Green River, LDW bed sediments, and LDW laterals) and local lateral sources (e.g., stormwater and CSO discharges) that drain directly to the EW.

Based on results of the LDW sediment transport model (QEA 2008), the total estimated sediment/solids load transported from the Green River and the LDW to the junction prior to the split between EW and WW over the 30-year simulation was 3,241,390 metric tons, with 3,215,850 metric tons from the Green River (99.2% of total), 7,840 metric tons from eroded bed sediments from river flows within the LDW (0.2% of total), and 17,770 metric tons from LDW lateral sources (0.6% of total) (AECOM 2012). Results from the LDW sediment transport model (QEA 2008) indicate that essentially 100% of the incoming upstream load to

[51] In this report, critical shear stress is defined as a property of the in situ bed sediments. It represents the value of shear stress (applied to that bed due to current velocities) at which the bed sediment would begin to mobilize (e.g., erode).

the EW from the Green River and LDW (bed sediments and lateral inputs) consist of silts and clays.[52] The percentage of flow from the LDW that enters the EW was evaluated in the EW STER (Anchor QEA and Coast & Harbor Engineering 2012) as varying between 50% (for 2-year flows and below) and 30% (for flows greater than the 2-year event). Assuming that the split in suspended sediment load between the EW and WW follows the split in flow, and using the average mass per year (over the 30-year simulation time of the LDW model), the annual average sediment loads transported into the EW from upstream are predicted to be as follows:[53]

- Green River source: 32,159 to 53,598 metric tons per year[54]
- Eroded bed sediments in the LDW: 78 to 131 metric tons per year
- Lateral sources within the LDW: 178 to 296 metric tons per year

Solids inputs to the EW from local lateral sources include contributions from SDs, CSOs, and runoff from the adjacent bridges and port aprons (see FS Figure 2-1 and Figure 2 of Appendix B, Part 1). Current conditions solids loading (annual) for EW lateral sources was estimated as part of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012). Annual solids loading from EW lateral sources based on likely future source control actions were developed as part of the FS and are discussed in Appendix B, Part 1. Future source control actions that will result in reduced solids loadings from lateral sources include CSO Control Plans that include both treatment and reduction in flow. A base case and low and high bounding cases for annual solids loads were estimated for both current and future conditions for EW lateral sources. Based on these bounding cases, the range of annual solids load to the EW from EW lateral sources is as follows:

- Current conditions: 45 to 114 metric tons per year
- Future conditions: 21 to 80 metric tons per year

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[52] This assumption was made based on results of the LDW sediment transport model (QEA 2008), which predicts that effectively all of the upstream sediment load input to the EW consists of fine particles (silts and clays), which should be well distributed in the water column.

[53] This estimate is not quantifying what settles in the EW from upstream; only a portion of these solids will settle in the EW.

[54] Range in values based on range in the estimated split in flow between the EW and WW; 30% to 50% of flow from LDW to EW.

5.1.2 Net Sedimentation Rates

Net sedimentation rates[55] were estimated as part of the FS using geochronology core samples and the predicted scour within the vessel operational areas defined as part of the EW STE and shown in Figures 5-1 and 5-2. Evaluation to determine the net sedimentation rate in the EW conducted as part of the EW STE and EW SRI was updated during the FS, and the revised net sedimentation rates for the EW are documented herein.

Geochronology core sampling included field collection of subsurface sediment cores from 22 locations located throughout the EW, and testing for Cs-137 and Pb-210 (Figure 2-13). Cores were placed in areas that had not been recently dredged, and in areas representative of different hydrodynamic regimes (Anchor QEA 2009). The geochronology core collection effort resulted in 18 recovered cores (including Core GC-20, which had low recovery) and four cores that had no recovery due to surface sediment conditions (i.e., gravel) at those locations (GC-4, GC-17, GC-21, and GC-22). The unrecovered cores were located adjacent to the Olympic Tug and Barge facility and T-18 in the Main Body Reach, along the center line of the Junction Reach, and within the Sill Reach of the EW (see Figure 5-1).

The geochronology analysis was done by evaluating the vertical profiles of Cs-137 and Pb-210 activities, which are used to age-date sediments and estimate net sedimentation rates in estuarine and freshwater systems (Olsen et al. 1978; Orson et al. 1990). Net sedimentation rates estimated from recovered cores[56] using these methods are provided in Table 3-3 of the EW SRI (Windward and Anchor QEA 2014). A summary of net sedimentation rates is provided below:

- Net sedimentation rates estimated from recovered cores using Cs-137 data range from 1.1 to greater than 2.0 cm/yr, with an average of 1.6 cm/yr. The range of sedimentation rates estimated from Cs-137 data for individual cores was relatively narrow compared to the Pb-210 data, and is therefore considered less uncertain than the Pb-210 data, when it was available.

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[55] The net sedimentation rate is the rate of sediment deposition (cm/yr), taking into account erosion and accretion processes at the site.

[56] Some recovered cores (GC-01, GC-03, GC-06, and GC-07) were archived and were not analyzed based on discussions with EPA, as documented in the EW SRI (Windward and Anchor QEA 2014).

- Net sedimentation rates estimated from recovered cores using Pb-210 data range from 0.1 to 4.2 cm/yr, with an average of 0.5 cm/yr. The range of sedimentation rates estimated from Pb-210 data for individual cores was greater than from Cs-137 data, and is therefore considered more uncertain than the Cs-137 data, when both estimates were available.
- The average net sedimentation rate from recovered cores is 1.6 cm/yr based on Cs-137 data, and 0.5 cm/yr based on Pb-210 data.
- Areas where cores were not recovered are assumed to have a net sedimentation rate of 0 cm/yr (no net sedimentation).

Spatially variable net sedimentation rates within the EW were assigned based on the vessel operational areas (defined in the STE) and geochronology core data. Figure 5-1 shows the locations of the vessel operational areas, geochronology cores (both recovered and unrecovered), and the representative net sedimentation rate assigned to each area. Representative net sedimentation rates were defined for each area based on the following methodology:

- Each vessel operational area was assigned a representative net sedimentation rate of 0 cm/yr, 0.5 cm/yr (average of recoverable cores for Pb-210 data), or 1.6 cm/yr (average of recoverable cores for Cs-137 data).
- Vessel operational areas that had recoverable cores within the area were assigned one of the representative net sedimentation rates based on those core data.
- If Cs-137 data were available within the vessel operational area, then net sedimentation rates were chosen using that data. Vessel operational areas that had no Cs-137 data peak measured were assigned a representative net sedimentation rate based on the Pb-210 data. Cs-137 data were prioritized over Pb-210 data due to higher uncertainty in Pb-210 data analysis for net sedimentation rate.
- Vessel operational areas that did not have any cores attempted within them, or had archived cores that were not analyzed, were assigned one of the representative net sedimentation rates based on adjacent areas, also considering other lines of evidence (e.g., estimated vessel scour). Similar to areas where cores were collected, the average of the Cs-137 data were prioritized over the average of the Pb-210 data due to higher uncertainty in Pb-210 data analysis for net sedimentation rate.
- If an unrecovered core was located in a vessel operational area (and no recovered cores were located within that area), the area was assigned a 0 net sedimentation rate.

- If an unrecovered core and a recovered core were located within the same vessel operational area, best professional judgement was used to assign an appropriate representative net sedimentation rate for that area.
- Estimated vessel scour depths associated with patterns of vessel use (Figure 5-2) and bathymetry (Figure 2-3b) were also used as a line of evidence for distinguishing net sedimention rates in adjacent operational areas.

Table 5-1 provides a summary of net sedimentation rates defined for each vessel operational area using the above approach.

For use in the predictive modeling efforts (Section 5.3 and 5.4) a site-wide net sedimentation rate was estimated based on the individual core net sedimentation rates. The site-wide net sedimentation rate for the EW FS of 1.2 cm/yr was estimated based on an area-weighted average of the representative net sedimentation rates for each vessel operational area shown in Figure 5-1 and listed in Table 5-1.

There is uncertainty in the assumption of average net sedimentation rate in the EW based on the range of net sedimentation rates measured by geochronology cores, impacts of vessel operations within the EW, and the methodology used to assign representative net sedimentation rates to each vessel operational area. The impacts of the uncertainty in the assumption for average net sedimentation rate on the results of the FS evaluation of site performance over time are evaluated through a sensitivity and bounding analyses described in Appendix J.

Table 5-1
Net Sedimentation Rates Defined by Vessel Operational Area

Propwash Area	Area (square feet)	Geochronology Cores Located in Area	Net Sedimentation Rate (in cm/yr) Range Based on Cs-137 Data (see Table 3-3 in EW SRI[a])			Net Sedimentation Rate (in cm/yr) Range Based on Pb-210 Data (see Table 3-3 in EW SRI[a])			Net Sedimentation Rate Assigned[b,c] (cm/yr)	Basis
			Via Cs-137 Peak	Low	High	Estimate Based on Best-Fit Line	Low	High		
1A-1	273,332	None	No Data (previously dredged area)			No Data (previously dredged area)			1.6	Average of the Cs-137 data, consistent with adjacent area (Area 5).
1A-2	286,107	None	No Data (previously dredged area)			No Data (previously dredged area)			1.6	Average of the Cs-137 data, consistent with adjacent areas to the south and moderate propeller wash forces in this area compared to Area 1A-3 (which has higher propeller wash forces; Figure 5-2).
1A-3	283,699	GC-08	No Peak			0.28	0.20	0.49	0.5	Average of the Pb-210 data, due to core GC-08 having Pb-210 data but no Cs-137 peak. In addition, the area is adjacent to the area with no recovery (Area 1A-4), but no bathymetric evidence of sediment propeller wash is present in this area (Figure 2-3b).
1A-4	271,317	GC-03	Archived			Archived			0	Net sedimentation rate set to 0 due to both an unrecovered core (GC-04) and predicted high scour rates from propeller wash in this area (Figure 5-2). This is also consistent with bathymetric evidence of propeller wash (Figure 2-3b).
		GC-04	Unrecovered			Unrecovered				
		GC-06	Archived			Archived				
1A-5	224,452	GC-01	Archived			Archived			0.5	Average of the Pb-210 data, due to the area having a recoverable core (which was archived), being adjacent to the area with no recovery (Area 1A-4), and having similar predicted propeller wash forces as Areas 1A-3 and 1A-4. No bathymetric evidence of sediment propeller wash is present in this area (Figure 2-3b).
1A-6	415,855	None	No Data (previously dredged area)			No Data (previously dredged area)			1.6	Average of the Cs-137 data, consistent with adjacent areas. This area is predicted to have propeller wash forces similar to Areas 1A-1, 1A-2, and 4A (Figure 5-2).
1B-1	870,200	GC-07	Archived			Archived			1.6	Average of Cs-137 data. Area 1B-1 had a recoverable core (which was archived) and is part of the navigation channel servicing T-18 Berths 3 and 4 (Areas 1A-1 and 1A-2), T-30 (Area 1A-6), T-25 (Area 4A), and Slip 27 (Area 3), and therefore is assigned the same sedimentation rate as these areas.
1B-2	870,200	GC-05	No Peak			0.67	0.26	0.67	0.5	Average of the Pb-210 data, due to core GC-05 having Pb-210 data but no Cs-137 peak. In addition, the area is part of the navigation channel that services the larger vessels that use T-18 Berths 1 and 2 (Areas 1A-3 through 1A-5), and therefore is assigned the same sedimentation rate as these areas that also have recoverable cores (i.e., Areas 1A-3 and 1A-5).
1C	403,971	None	No Data			No Data			1.6	Average of Cs-137 data, because sedimentation rate is consistent with adjacent areas to the north and south, and Area 1C is not expected to have large propeller wash forces compared to T-18 Berths 1 and 2 and the adjacent navigation channel (Figure 5-2).
2	301,364	GC-02	No Peak			Low Correlation			1.6	Average of Cs-137 data, consistent with Area 3 (another slip) that suggests selection of a higher range net sedimentation rate for this area.
3	215,033	GC-09	No Peak			0.56	0.35	1.4	1.6	Average of Cs-137 data. Cs-137 and Pb-210 data in this area suggest selection of a higher range net sedimentation rate for this area.
		GC-10	1.3	1.2	1.4	0.61	0.3	0.61		
4A	359,473	GC-13	No Peak			0.69	0.34	0.69	1.6	Average of Cs-137 data. Although core GC-13 only had a Pb-210 peak, the area is expected to have a higher sedimentation rate due to proximity to the narrow to wide waterway transition and the data in adjacent Areas 4B and 6-2. Cs-137 data used because nearby core GC-12 includes Cs-137 sedimentation rates but has a lower Pb-210 sedimentation rate than core GC-13, indicating the sediment rates are similar in these two areas (i.e., Areas 4B and 4A).
4B	412,584	GC-12	>1.9	1.8	2.0	0.46	0.27	1.8	1.6	Average of Cs-137 data due to Cs-137 peak.
		GC-16	1.6	1.2	1.4	Low Correlation				
5	356,623	GC-11	>1.7	1.6	1.8	0.47	0.27	1.8	1.6	Average of Cs-137 data due to Cs-137 peak.
		GC-15	1.3	1.1	1.3	Low Correlation				

Table 5-1

Net Sedimentation Rates Defined by Vessel Operational Area

Propwash Area	Area (square feet)	Geochronology Cores Located in Area	Net Sedimentation Rate (in cm/yr) Range Based on Cs-137 Data (see Table 3-3 in EW SRI[a])			Net Sedimentation Rate (in cm/yr) Range Based on Pb-210 Data (see Table 3-3 in EW SRI[a])			Net Sedimentation Rate Assigned[b,c] (cm/yr)	Basis
			Via Cs-137 Peak	Low	High	Estimate Based on Best-Fit Line	Low	High		
6	181,099	GC-17	Unrecovered			Unrecovered			0.5	Average of Pb-210 data. Cs-137 data from core GC-18 suggests a higher net sedimentation rate, but core GC-17 was unrecoverable in this area, which suggests a moderate net sedimentation rate.
		GC-18	>1.9	1.8	2.0	Low Correlation				
		GC-20	Low Recovery			Low Recovery				
6-2	66,247	GC-16	1.6	1.5	1.7	0.18	0.09	4.2	1.6	Average of Cs-137 data due to Cs-137 peak.
7	86,233	GC-19A	1.2	1.1	1.3	Low Correlation			1.6	Average of Cs-137 data due to Cs-137 peak.
8	93,598	GC-21	Unrecovered			Unrecovered			0	Net sedimentation rate set to 0 due to two unrecovered cores in area.
		GC-22	Unrecovered			Unrecovered				

Notes:

a. East Waterway (EW) Supplemental Remedial Investigation (SRI) (Windward and Anchor QEA 2014).

b. One of three values were assigned to each of the areas: 0 cm/yr, 0.5 cm/yr, or 1.6 cm/yr, representing no sedimentation, moderate sedimentation based on the average of Pb-210 data, and higher sedimentation based on the average of Cs-137. As discussed in Section 5.1.2, the Cs-137 data are considered more reliable than the Pb-210 and serve as the default in areas without additional data. Shading in the table matches shading in net sedimentation areas shown in Figure 5-1.

c. Site-wide area-weighted net sedimentation rate is 1.2 cm/yr.

cm/yr – centimeters per year
Cs-137 – cesium-137
Pb-210 – lead-210
T – Terminal

5.1.3 Solids Balance Into and Out of the East Waterway

A numerical sediment transport model that evaluates fate and transport of both upstream and EW lateral sources was not developed as part of the EW STER due to the impacts of vessel operations on localized sediment transport in the EW (Anchor and Battelle 2008). Therefore, using estimates of upstream and EW lateral solids loading into the EW (Section 5.1.1) and the average net sedimentation rate in the EW developed from geochronological core data (Section 5.1.2), an estimate of the amount of solids from upstream settling into, and passing out of (i.e., solids mass balance), the waterway was made. This information was used as input to the site performance evaluation. The impacts of the uncertainties associated with estimates of upstream solids loading to the EW on the results of the evaluation are discussed in Appendix J.

In order to estimate the solids mass balance for upstream inputs, a series of steps were undertaken. First, hypothetical net sedimentation rates were calculated assuming that the entire incoming solids load (from upstream and lateral sources within the EW) settled evenly in the EW (including Slips 27 and 36). The total mass loading from upstream and lateral sources into the EW is between approximately 32,500 and 54,176 metric tons per year.[57] This total is based on the 30% to 50% proportion of the total LDW flow predicted by the hydrodynamic model to flow into the EW.[58] The mass load into the EW was converted to a volume by setting the density of the incoming sediment load to the average in situ surface sediment densities measured by the SEDflume core evaluation (1.5 grams per cubic centimeter [g/cm^3]; Anchor QEA and Coast & Harbor Engineering 2012). This mass was then evenly distributed over the entire EW to calculate a hypothetical net sedimentation rate representing a 100% solids retention in the EW. Net sedimentation rates estimated in this manner range between 3.6 and 6.0 cm/yr. The site-wide average net sedimentation rate calculated for the EW (see Section 5.1.2),1.2 cm/yr, was subtracted from these hypothetical sedimentation rates to estimate the percent of incoming solids load that is likely transported out of the EW. This calculation suggests that between 67% and 80% of the sediment load

[57] This is the range in upstream sediment load with the solids load developed for the PTM (current conditions) added.

[58] This assumes that the suspended solids load is the same as the split in flow between EW and WW.

that enters the EW is transported out of the EW and, conversely, that 20% to 33% of the incoming sediment load is retained within the EW.

5.1.4 Scour Potential from High Flow Events

As part of the EW STE, SEDflume cores were collected to evaluate the critical shear stress of surface sediments within the EW.[59] The range in critical shear stresses in the EW based on the 95% confidence interval for the SEDflume data evaluation is 0.20 to 0.37 Pascals (Pa).

Scour potential from high flow events was evaluated as part of the EW STE using critical shear stress values estimated from SEDflume data and bed shear stresses estimated from hydrodynamic model results from the hydrodynamic model simulations completed as part of the EW STE.[60] These estimates of bed shear stress were compared to critical shear stress estimates of in situ sediments obtained from SEDflume cores to evaluate erosion potential within the EW due to tidal and riverine currents based on a typical spring tide and mean annual flows through the 100-year upstream flow event (upstream flow rate of 12,000 cfs). The calculated maximum values of bed shear stress ranged from 0.05 Pa for mean annual upstream flow to 0.12 Pa for the 100-year upstream flow event.

Because the maximum bed shear stress predicted by the model for all flow events is at least 35% below the lower confidence bound value for critical shear stress (0.20 Pa) as estimated from the SEDflume core data, it is anticipated that significant bed scour or erosion of in situ bed sediments within the EW will not occur as a result of tidal or riverine currents.

5.1.5 Scour Potential from Vessel Operations

The majority of the EW is subject to vessel operations that impact bed sediment movement. As part of the EW STER, a study was conducted to define typical and extreme vessel operations in the EW and develop estimates of maximum near-bed velocities and associated bed shear stresses within the EW due to vessel operations. The results and assumptions associated with the vessel operation study (including operational areas and vessel

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[59] See Section 6.1.3 of the STER (Anchor QEA and Coast & Harbor Engineering 2012).

[60] See Section 6.2.1 of the STER (Anchor QEA and Coast & Harbor Engineering 2012).

information) are provided in Section 5.1.2 of the STER (Anchor QEA and Coast & Harbor Engineering 2012).

As part of the FS, the calculated bed shear stresses associated with vessel operations (Anchor QEA and Coast & Harbor Engineering 2012) were used to estimate scour depths within the EW. Propwash-induced bed shear stresses due to steady state[61] docking procedures estimated for all defined vessel operations and associated operational areas in the EW range from 2 to 23 Pa. The 95th percentile confidence interval of critical bed shear stress for surface sediments in the EW (from SEDflume core data) ranges between 0.20 and 0.37 Pa. Based on the scour evaluation in the STER (Section 5.1), surface sediments within the waterway have the potential to be eroded due to vessel operations at varying depths ranging from 0.3 to 4.7 feet (based on both typical and extreme vessel operations) throughout the majority of the EW. Scour estimates were calculated using steady state assumptions, and represent conservatively high estimates of scour based on defined vessel operations (see Section 5.1.2 of the STER).

Table 5-2 provides a summary of maximum near bed velocities, bed shear stresses, and predicted scour depths within the EW for the various vessel operational areas. Figure 5-2 shows the spatial variation of predicted scour depths within the EW and identifies the locations of the various vessel operational areas identified in Table 5-2. Additional information on the scour calculations are described in a technical memorandum included in Appendix B, Part 2 of this FS.

[61] For evaluating potential shear stresses and scour depths associated with propwash, it was conservatively assumed that the propwash was "steady state"; the propwash reached the maximum velocity over the largest area.

Table 5-2
Predicted Maximum Bed Shear Stress and Scour Depths Due to Vessel Operations

Vessel Operating Area[1]	Dominant Vessel Operations in Area[1]	Maximum Near-bed Velocity[2] (ft/s)	Maximum Bed Shear Stress[2] (lb/ft^2(Pa))	Maximum Predicted Scour Depth[3,4] (ft)
Areas 1A-3, 1A-4, and 1A-5 (Terminal 18: Berths 1 and 2)	Berthing, large container vessels	11.4	0.48 (23)	4.7
Areas 1A-1, 1A-2, and 1A-6 (Terminal 18: Berths 3 and 4 and portions of Terminal 30)	Berthing, small container vessels	7.1	0.19 (9)	2.8
Areas 1B-1 and 1B-2[5]	Transit in Federal Navigation Channel	3	0.03 (2)	2.8 – 4.7
Area 1C	No berthing area	3	0.03 (2)	0.3
Area 2 (Slip 36)	Berthing, U.S. Coast Guard vessels	6.5	0.16 (8)	2.3
Area 3 (Slip 27)	Barge/tug operations	3	0.03 (2)	0.7
Area 4A (existing operations)	Barge/tug operations	3	0.03 (2)	NA
Area 4A (future operations)	Berthing, small container vessels	9.0	0.30 (14)	2.8
Area 4B	Transit in Federal Navigation Channel	3	0.03 (2)	0.7
Area 5	Berthing, smaller bulk carriers	3	0.03 (2)	0.7
Area 6	Barge/tug operations	10.6	0.45 (22)	2.9
Area 7	Barge/tug operations, no berthing area	4.7	0.08 (4)	0.9
Area 8	Berthing, tugs (no commercial operations)	4.2	0.07 (3)	1.1

Notes:
1. Vessel operating areas and detailed operations information can be found in Section 5.1.2 and Table 5-2 of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).
2. Calculations for maximum near-bed velocities and shear stresses are discussed in Section 5.1.4 of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).
3. Calculations for maximum predicted scour depth are provided in Appendix B, Part 2.
4. Predicted scour depths throughout the EW are shown in Figure 5-2.
5. Area 1B represents the navigation area between Terminal 18 and 30 berthing areas. Since berthing maneuvers may begin within the navigation channel depending on weather or other site conditions, this area is expected to experience similar scour depths as the berthing areas.

EW – East Waterway
ft/s – feet per second
lb/ft^2 – pounds per square foot
NA – not applicable
Pa – Pascals
STER – Sediment Transport Evaluation Report

5.2 Post-construction Sediment Bed Replacement Value and Dredge Residuals

The sediment replacement value represents the post-construction surface sediment bed concentration in the biologically active zone (BAZ; top 10 cm) following remediation in the EW. The replacement value is used to derive SWACs, which are used to derive an initial surface sediment concentration for evaluating the site performance over time (Section 5.3) and recontamination potential associated with each alternative (Section 5.4). The replacement value only represents the initial (or Time 0) sediment condition following completion of all remedial construction activities; that is, dredging and placement of residuals management cover (RMC), capping, or ENR. The need for RMC placement will be determined based on post-dredge monitoring, but is assumed for modeling purposes to be placed over all of the dredging area plus immediately adjacent areas (see Section 2 of Appendix B, Part 3A).

Experience at other sediment remediation sites has shown that contaminant concentrations in the sediment bed after completing a remedial action (e.g., dredging or partial dredging and capping) cannot be assumed to be zero (NRC 2007; EPA 2005). This occurs because of several factors: 1) residual surface contamination always exists from the resettling of contaminated sediments suspended during remedial activities; and 2) material used for RMC following dredging may contain low concentrations of key risk driver COCs. In addition, as described in Section 5.1.5, propwash from large ships in the EW will also mix dredge residuals, RMC, and existing sediments around the site.

Detailed evaluation and calculated values of dredge residuals and associated bed replacement values for dredging activities and other proposed remedial technologies are provided in Part 3A of Appendix B.

5.3 Site-wide Evaluation of Site Performance Over Time

The evaluation of the site performance over time will be based on predictions of the concentrations of human health risk driver COCs in surface sediment over time following remediation due to future sediment deposition and vertical mixing processes. The long-term surface sediment predictions will provide information to assess whether the remedial alternatives are likely to remain effective at meeting RAOs. These long-term predictions take into account upstream and lateral inputs to the EW. This evaluation will be used to predict whether the EW remedial alternatives remain effective in the long term (e.g., 10, 20, and 30 years post-construction) at meeting human health and ecological RAOs.

The site performance over time evaluation will be used to predict changes to the EW site-wide SWAC[62] (from Time 0 as determined in the short-term effectiveness evaluation) over time (years 1 through 40) for the four human health risk driver COCs (total PCBs,[63] arsenic, cPAHs, and dioxins/furans) for each remedial alternative based on anticipated solids deposition and vertical mixing (from propwash and bioturbation) in the EW. This evaluation will be referred to as the box model evaluation. Only these four risk drivers will be analyzed in this way because their compliance is measured as a site-wide average concentration.

The SWAC after construction completion and over time is dependent on remedial alternative, physical processes within the EW, and upstream and lateral inputs to the EW. Specific elements that were considered for the box model evaluation include the following:

- Time 0 surface sediment chemistry based on proposed alternatives, including replacement values for remediated and interior unremediated areas (Section 5.2), along with current sediment bed concentrations in other areas, such as underpier and areas below RALs along the north and south boundaries of the OU).
- Bed mixing depths due to propwash and bioturbation (varies within the EW). Armor rock and sediment protected by armor rock in the various alternatives are assumed not to mix.
- An assumed average net sedimentation rate within the EW determined from geochronology core data (see Section 5.1.2). For the purpose of evaluation of site-wide SWAC values, a constant value was applied for the entire EW, and all solids sources to the EW are assumed to settle evenly throughout the EW. This simplifying assumption is appropriate for calculating site-wide average concentrations within the EW.

[62] Spatially-weighted average concentrations (SWACs) are average concentrations in an area of interest calculated by interpolating data over a specified area such that each individual concentration value is weighted in proportion to the sediment area it represents. SWACs are used to estimate exposure point concentrations to assess risk to human or ecological receptors and for estimating the effectiveness of the alternatives at reducing that risk.
[63] Total PCBs are also a risk driver COC for fish and will be assessed on a site-wide basis like the human health COCs based on seafood consumption.

- Contribution to net sedimentation rate in the EW from EW lateral sources and upstream sources (Green River, LDW bed sediment, and lateral inputs).
- Chemistry for each input: bed replacement value for remediated areas, unremediated area, Green River, LDW bed sediment and lateral sources, and EW lateral sources.

The effects of future dredging activities were not taken into account in this evaluation because the need, location, and timing of maintenance dredging activities are unknown and may vary over time. In addition, the purpose of the evaluation is to compare the relative performance of the remedial alternatives against each other. Maintenance dredging activities are expected to have similar effects on all proposed alternatives.

Specific calculations for each alternative include three specific evaluations as follows:

- Incoming Solids Concentrations: Estimate total solids loading to the EW from upstream and lateral sources and their corresponding chemical concentrations
- Define Site-wide Surface Sediment SWAC (years 1 to 40): SWAC covering the entirety of the EW OU
- Define Site-specific Surface Sediment SWAC in Target Areas (years 1 to 40): Underpier and intertidal clamming areas

These evaluations are described in more detail in the following sections. Uncertainty associated with input values and methodology on the results of the box model evaluation is discussed in Appendix J.

5.3.1 Chemistry Assumptions for Upstream and East Waterway Lateral Sources

Chemistry assumptions for upstream (Green River, LDW bed sediment, and LDW lateral sources) and EW lateral sources were developed for the four human health risk driver contaminants (total PCBs, cPAHs, dioxins/furans, and arsenic) evaluated as part of the box model evaluation.

Chemistry assumptions for Green River input considered the same datasets for use in the LDW (AECOM 2012), but selected different concentrations of certain parameters due to a lower percentage of coarse-grained sediment entering the EW from upstream. A discussion of how chemistry values were developed for the Green River is provided in Appendix B, Part 3B. Since the assembly of the Green River datasets used for the LDW FS, new data have been collected on the Green River (King County 2016; USGS 2016). Model input values have not been updated to include these new data for several reasons, as follows:

- The U.S. Geological Survey (USGS) is still reviewing and processing their data, which will be made available when their report is completed.
- Data from both USGS and King County studies are within the range of values previously used in the modeling, and therefore incorporating these new data would lead to results within the range presented in the sensitivity and bounding analysis in Section 2.3 of Appendix J.
- Any changes in results associated with incorporating the new data into additional modeling would have an equal bearing on all alternatives, and therefore would not affect the conclusions of this FS.

The new data are summarized in Appendix B, Part 3B.

Base case assumptions for LDW bed sediment and LDW lateral sediment sources were taken from values provided in the LDW FS (AECOM 2012). Bounding values were available for LDW lateral sources based on the LDW FS for the four human health risk driver COCs; however, these were not incorporated into the sensitivity analysis because the impact of LDW lateral sources on net upstream concentrations entering the EW are minor compared to the Green River concentrations (i.e., sensitivities are captured by the Green River bounding values). Chemistry assumptions for the LDW bed sediment were based on the baseline SWAC when available in the LDW FS (four human health risk drivers), and otherwise based on the baseline arithmetic average of LDW surface sediment samples (other five SMS contaminants). There was no bounding information in the LDW FS for LDW bed sediment site-wide; therefore, the base case for these input parameters were used for the bounding evaluation. Although the LDW is a cleanup site and will have lower concentrations in bedded sediment following cleanup, the current conditions were used for modeling because, like LDW laterals, the impact of LDW bed sediment on net upstream concentrations entering the EW are minor compared to the Green River concentrations. The Green River bounding evaluation captures any potential changes in the LDW bed sediment.

EW lateral sources were divided into two categories—SDs and CSOs—and separate chemistries were developed for each category as described in Appendix B, Part 4. Seeps and shoreline sheetflow are minor sources compared to lateral storm drains and CSOs in the EW, and were not included in the box model evaluation (see Section 2.11.3). These pathways will be assessed further during the design phase and through source control actions. Assumptions for both current and potential future chemistry conditions were developed for EW lateral sources (i.e., SDs and CSOs). Chemistry values for potential future conditions differed compared to current conditions for some COCs for SDs based on likely future source control efforts.[64] A base case and low and high bounding chemistry assumptions were developed for all EW lateral sources.

Values for chemistry assumptions for all incoming solids used for the box model evaluation are provided in Table 5-3.

Table 5-3
Chemistry Assumptions for Upstream and East Waterway Lateral Source Solids for the Site Performance Over Time Evaluation

Inputs	COC[1]			
	Arsenic (mg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Total PCBs (µg/kg dw)[2]	Dioxin/Furan TEQ (ng TEQ/kg dw)
Current Conditions				
EW CSOs[3] - Base	5	680	260	16
EW CSOs[3] - Low	6	430	240	7.6
EW CSOs[3] - High	9	1500	630	37
EW SDs[3] - Base	10	1300	250	27
EW SDs[3] - Low	9	480	55	12
EW SDs[3] - High	20	1900	450	53
LDW Laterals[4]	13	1400	300	20
LDW Bed[4]	15	380	340	26
Green River[5] - Base	9	135	42	6
Green River[5] - Low	7	40	5	2
Green River[5] - High	10	270	80	8
Future Source Control Conditions (EW Laterals)[6]				

[64] No changes were assumed for future conditions for CSO chemistry; however, changes were assumed for solids input due to CSO control plans (see Appendix B, Part 5 for details).

Table 5-3
Chemistry Assumptions for Upstream and East Waterway Lateral Source Solids for the Site Performance Over Time Evaluation

Inputs	COC[1]			
	Arsenic (mg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Total PCBs (µg/kg dw)[2]	Dioxin/Furan TEQ (ng TEQ/kg dw)
EW CSOs[3] - Base	5	680	260	16
EW CSOs[3] - Low	6	430	240	7.6
EW CSOs[3] - High	9	1500	630	37
EW SDs[3] - Base	10	**950**	**190**	**22**
EW SDs[3] - Low	9	480	55	12
EW SDs[3] - High	20	1900	450	**45**
LDW Laterals[4]	13	1400	300	20
LDW Bed[4]	15	380	340	26
Green River[5] - Base	9	135	42	6
Green River[5] - Low	7	40	5	2
Green River[5] - High	10	270	80	8

Notes:
1. Long-term effectiveness evaluation conducted only for the four human health risk driver COCs.
2. For reference, a total PCBs concentration of 192 µg/kg dw is equivalent to 12 mg/kg OC based on average TOC of 1.6% in EW surface sediments.
3. Methodology for determining values for EW CSOs and SDs provided in Appendix B, Part 4.
4. Values for LDW Bed and Laterals are taken from the LDW FS (AECOM 2012).
5. Methodology for determining values for the Green River provided in Section 5.3.1 and Appendix B, Part 3B.
6. Values are the same as current conditions (grey text) except where noted (**bold black text**).

µg/kg – micrograms per kilogram
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EW – East Waterway
FS – Feasibility Study
LDW – Lower Duwamish Waterway
mg/kg – milligrams per kilogram
ng – nanograms
PCB – polychlorinated biphenyl
SD – storm drain
TEQ – toxic equivalent
TOC – total organic carbon

5.3.2 Incoming Solids Concentrations

Incoming solids concentrations were calculated for the four human health risk driver COCs using chemistry assumptions provided in Table 5-3 and estimates of annual deposition (mass) from upstream and EW lateral sources. Solids deposited in the EW from these sources were estimated as described below, and are summarized in Table 5-4. Sources of solids to the EW included in the incoming solids concentration calculations are upstream sources (Green River, LDW bed sediment, and LDW lateral inputs) and EW lateral inputs (SDs and CSOs). Deposition from these solids sources is assumed to be evenly distributed throughout the EW for the calculations.

An average net sedimentation rate for the EW was estimated using measured rates from geochronological cores as explained in Section 5.1.2. For evaluation purposes, this average net sedimentation rate was assumed to be consistent throughout the EW (the same rate applied everywhere); approximately 1.2 cm/yr.[65] Using the net sedimentation rate and an assumed density of the deposited sediment (taken from site-specific SEDflume core data), the total volume of deposited solids in the EW (on an annual basis) can be estimated. The impacts of this assumption on the predicted SWAC values were evaluated as part of a sensitivity evaluation that is discussed in detail in Appendix J.

This total volume of deposition was partitioned into contributions from the Green River, LDW bed sediment and lateral sources, and EW lateral inputs. Table 5-4 illustrates how this partitioning is done for current and future conditions, and the steps taken for current conditions are described below:

[65] The impacts of uncertainty in assumption of assumed net sedimentation rate on the results of the evaluation are discussed in Appendix J.

Table 5-4
Calculation of Net Sedimentation Rates used for the Site Performance Over Time Evaluation

Model Run	EW Lateral Solids Deposited in EW (kg/yr)	EW Lateral Solids Deposited in EW (cm/yr)	Measured Average NSR (current conditions (cm/yr)	% of EW Lateral Solids Contributed to NSR (%)	Annual Deposition from All Upstream Sources (cm/yr)	Annual Deposition From Green River (99.21% of Total Upstream Sources) (cm/yr)	Annual Deposition from LDW Bed (0.55% of Total Upstream Sources) (cm/yr)	Annual Deposition from LDW Laterals (0.24% of Total Upstream Sources) (cm/yr)	Calculated Average NSR for EW (future conditions) (cm/yr)
Base Case, Current	84,630	0.009	1.2	0.8%	1.191	1.182	0.0066	0.0029	NA
Lower Bound, Current	45,475	0.005	1.2	0.4%	1.195	1.186	0.0066	0.0029	NA
Upper Bound, Current	114,117	0.012	1.2	1.0%	1.188	1.179	0.0065	0.0029	NA
Base Case, Future	49,527	0.005	NA	0.4%	1.191	1.182	0.0066	0.0029	1.196
Lower Bound, Future	21,578	0.002	NA	0.2%	1.195	1.186	0.0066	0.0029	1.197
Upper Bound, Future	80,760	0.008	NA	0.7%	1.188	1.179	0.0065	0.0029	1.196

Notes:
cm/yr – centimeters per year
EW – East Waterway
kg/yr – kilograms per year
LDW – Lower Duwamish Waterway
NA – not applicable
NSR – net sedimentation rate

- The total mass of solids (in kilograms per year [kg/yr]) deposited in the EW from EW lateral inputs for current conditions (SDs and CSOs) is calculated from PTM results by adding all of the deposition predicted by the model within the EW.
- Using an assumed density of solids (1.5 g/cm^3),[66] the total mass of solids deposited in the EW from EW lateral sources is transformed to cm/yr.
- The calculated deposition rate for EW lateral inputs is subtracted from the total assumed net sedimentation rate for the EW determined from geochronology cores (1.2 cm/yr, see Section 5.1.2).
- The difference is assumed to represent the upstream solids contribution to the EW on an annual basis. The contribution from upstream solids sources to the total net sedimentation rate (as determined from geochronological cores) was evaluated in the absence of a full sediment transport model[67] to explicitly calculate the deposition rate from upstream sources alone.
- The upstream solids load consists of three sources: the Green River, LDW bed sediment, and LDW lateral inputs. The upstream deposition rate is divided between these three sources using solids loading to the EW predicted by the LDW sediment transport model (as described in the LDW FS; AECOM 2012).
- Different chemistry assumptions (see Table 5-3) are applied to each solids source as a post-processing step.

Solids loading to the EW were estimated for two conditions: current and future, where future conditions represent likely future source control actions applied to EW lateral sources (SDs and CSOs). These source control actions result in a reduction in the solids deposition in the EW from some EW lateral inputs and changes to chemistry in some SD solids. The solids contribution from upstream sources for future conditions is assumed to remain the same as current conditions. Overall, this assumption will result in a slightly lower total net sedimentation rate for future conditions in the EW than current conditions (as shown in Table 5-5). Current conditions solids loading will be applied to SWAC calculations for

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[66] Representative density of deposited sediment in the EW taken from SEDflume data (collected by Sea Engineering, Inc. as part of the STER; Anchor QEA and Coast & Harbor Engineering 2012).

[67] A full sediment transport model was not conducted as part of the EW FS because EW sediment transport processes are highly impacted by vessel operations, which resuspend bed sediments due to propwash.

years 1 through 10 post-construction, and potential future conditions solids loading will be applied to the SWAC calculations for years 11 through 30. This timeframe assumes that the likely future source control actions that affect solids loading from EW lateral sources will be in place at the time. This time marker is just an assumption for EW modeling; changes for EW lateral sources may occur before or after this time marker.

Incoming solids concentrations calculated for the four COCs (using chemistry assumptions provided in Table 5-3 and partitioning among sources in Table 5-4) are provided in Table 5-5.

5.3.3 Sediment Bed Mixing Assumptions

Vertical mixing assumptions used in the box model evaluation were developed based on predicted maximum scour depths in the EW. Maximum predicted scour depths in the EW are discussed in Section 5.1.5 and are provided in Figure 5-2 and Table 5-2. Vertical mixing assumptions were developed to produce conservatively high estimates of surface concentrations in most situations by setting mixing depth assumptions to a value equal to or less than predicted scour depths in each operational area. This increases the impact of dredge residuals on the average concentration of the sediments once they are mixed by reducing the mixed volume of cleaner sediments underlying the dredge residuals that are mixed. Vertical mixing assumptions for the box model evaluation are shown in Figure 5-3. Intertidal areas that are not subject to propwash have a maximum vertical mixing depth of 10 cm, which represents the typical bioturbation mixing depth in the EW. Concentrations of underpier sediments were calculated assuming that the total sediment volume located in underpier areas are fully mixed, rather than by a set vertical depth.

The spatial extent of the EW surface sediments that is mixed due to vessel operations in the EW is variable from year to year, and therefore difficult to predict with precision. However, based on understanding of vessel operations and evaluation of geochronology cores in the EW, an estimate of the portion of the EW subject to vertical mixing due to propwash was made for the FS. The box model evaluation included mixing due to propwash by defining the percent of the EW open-water surface area that is predicted to be vertically mixed (bed sediments) over the 5-year temporal increment used in the box model evaluation. The

Table 5-5
Incoming Solids Concentrations

Deposited Solids[1]	% of total[2]	Upstream: LDW Lateral 0.24%	Upstream: LDW Bed 0.55%	Upstream: Green 98.4% - 99.05%	EW Laterals: EW SDs 0.16% - 0.66%	EW Laterals: EW CSOs 0.01% - 0.20%	Total 100%
COC-Time	**Scenario**	**Chemistry Assumptions: LDW Lateral[3]**	**LDW Bed[3]**	**Green River[4]**	**EW SDs[5]**	**EW CSOs[6]**	**Incoming[6,7] Concentration**
PCB-*Current* (µg/kg dw)	Base Case	300	350	42	250	260	45.7
	Low Bounding			5	55	240	8.0
	High Bounding			80	450	630	85.6
PCB-*Future* (µg/kg dw)	Base Case			42	190	260	44.9
	Low Bounding			5	55	240	7.7
	High Bounding			80	450	630	84.5
cPAHs-*Current* (µg TEQ/kg dw)	Base Case	1,400	390	135	1300	680	146
	Low Bounding			40	480	430	47
	High Bounding			270	1900	1500	287
cPAHs-*Future* (µg TEQ/kg dw)	Base Case			135	950	680	142
	Low Bounding			40	480	430	46
	High Bounding			270	1900	1500	283
Arsenic-*Current* (mg/kg dw)	Base Case	13	16	9	10	5	9.05
	Low Bounding			7	9	6	7.07
	High Bounding			10	20	9	10.10
Arsenic-*Future* (mg/kg dw)	Base Case			9	10	5	9.05
	Low Bounding			7	9	6	7.07
	High Bounding			10	20	9	10.09

Table 5-5
Incoming Solids Concentrations

Deposited Solids[1]	% of total[2]	Upstream LDW Lateral	Upstream LDW Bed	Upstream Green	EW Laterals EW SDs	EW Laterals EW CSOs	Total
		0.24%	0.55%	98.4% - 99.05%	0.16% - 0.66%	0.01% - 0.20%	100%
COC-Time	**Scenario**	**Chemistry Assumptions LDW Lateral[3]**	**LDW Bed[3]**	**Green River[4]**	**EW SDs[5]**	**EW CSOs[6]**	**Incoming[6,7] Concentration**
Dioxin/Furan-*Current* (ng TEQ/kg dw)	Base Case	20	26	6	27	16	6.3
	Low Bounding			2	12	7.6	2.2
	High Bounding			8	53	37	8.5
Dioxin/Furan-*Future* (ng TEQ/kg dw)	Base Case			6	22	16	6.2
	Low Bounding			2	12	7.6	2.2
	High Bounding			8	45	37	8.3

Notes:
1. Methodology for determining volumes for deposited solids discussed in Sections 5.1.1 through 5.1.3.
2. See Table 5 in Appendix B, Part 1 for EW solids loads for all scenarios (base, low, and high for current and future conditions).
3. Values for LDW Bed and Laterals are taken from the LDW FS (AECOM 2012).
4. Methodology for determining values for the Green River provided in Section 5.3.1 and Appendix B, Part 3.
5. Methodology for determining values for EW CSOs and SDs provided in Appendix B, Part 4.
6. Incoming concentrations are calculated as a weighted average by mass for listed incoming sediment sources.

µg/kg – micrograms per kilogram
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EW – East Waterway
FS – feasibility study
LDW – Lower Duwamish Waterway
mg/kg – milligrams per kilogram
ng – nanograms
PCB – polychlorinated biphenyl
SD – storm drain
TEQ – toxic equivalent

percent of the EW surface area that was allowed to mix over the 5-year time period was varied as part of the sensitivity analysis in Section 2.4 of Appendix J.

The estimate for approximate percent of the EW area that is subject to frequent propwash mixing was based on the review of the geochronology cores and the assigned net sedimentation rates by vessel operational area shown in Figure 5-1 and Table 5-1. Vessel operational areas were determined to be mixed if one of the following were true (based on Table 5-1):

- Area had an unrecovered core
- Area had a low-correlation Pb-210 core
- Area had a core with no Cs-137 peak
- Area was assigned a 0.5 or 0 cm/yr net sedimentation rate

These criteria were assumed to be indicative of mixing processes occurring in the area. The sum of vessel operational areas that met one of the above criteria represent approximately 50% of the EW. This is an empirical approximation of a physical process that is variable over the EW area and from year to year, but is considered a reasonable estimate for the purpose of comparing relative performance of proposed remedial alternatives over time. As mentioned above, the impact of the assumptions on results of the box model evaluation were determined through a sensitivity analysis described in Section 2.4 of Appendix J.

5.3.4 Exchange of Open-water and Underpier Sediments

Vessel scour by propwash in open-water and underpier areas results in exchange of sediments between those two areas due to resuspension of sediments by propwash into the water column, subsequent transport by tidal and river currents, and deposition of the resuspended material. In order to account for this physical mechanism in the box model evaluation, a mechanism for exchange of sediments between the open-water and underpier areas was included in the model calculations. This exchange was parameterized as an exchange of an equal volume of material between open-water and underpier areas over the same timeframe as vertical mixing (5 years, see Section 5.3.3).

The volume of material exchanged was assumed to be a percent of the total underpier sediment volume;[68] and was estimated based on the length of the pier face within EW that is adjacent to a vessel operational area predicted to have large propwash scour depths (see Figure 5-2). This impacted pierface length is approximately 25% of the total pierface length within the EW. Therefore, 25% of the total volume of the underpier sediments was assumed to mix with open-water areas every 5 years. As with the percent of the EW surface area that is mixed, this is an empirical approximation of a physical process that is spatially and temporally variable over the EW, but is considered a reasonable estimate for the purpose of comparing relative performance of proposed remedial alternatives over time. The impact of the assumed value of exchange on results of the box model evaluation were determined through a sensitivity analysis described in Section 2.3.2 of Appendix J.

5.3.5 Percent Reduction in Bioavailability of Hydrophobic Organic Contaminants Due to In Situ Treatment

In order to evaluate the effect of in situ treatment placement (i.e., activated carbon [AC]), the percent reduction in bioavailability of hydrophobic organic contaminants (i.e., total PCBs, cPAHs, and dioxins/furans) due to in situ treatment was estimated. This parameter applies only to remedial alternatives that proposed in situ treatment in underpier areas. The model input values for bioavailability were determined through review of literature and pilot study results in consideration of effectiveness and stability of AC over time (see Section 7.2.7.1.1 of the FS). The best estimate used in the box model evaluation is 70% reduction in contaminant bioavailability from in situ treatment. This value is based on laboratory and field studies in stable sediment that have consistently shown typical bioavailability reductions of 70% to 99% (see Section 7.2.7.1). The 70% biolavailability reduction used for the box model was selected from the low end of the range to account for dilution of AC during mixing and exchange of underpier sediment. The effects of the estimate of reduction in bioavailability on site-wide SWACs were determined through a sensitivity analysis described in Section 2.4 of Appendix J.

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[68] The typical thickness of underpier sediments in the EW is approximately 2 feet (see Section 2.6) based on probing data, which equates to approximately 53,000 cubic yards of underpier sediments (see Section 2.2.2 of Appendix F).

5.3.6 Site-wide SWAC

A box model evaluation was used to predict the EW site-wide SWAC over time (years 0 through 40 following construction) for the four human health risk driver COCs (total PCBs, arsenic, cPAHs, and dioxins/furans) for each remedial alternative based on anticipated solids deposition and vertical mixing in the EW. For FS purposes, SWACs are used to estimate exposure point concentrations to assess risk to human or ecological receptors and for estimating the effectiveness of the alternatives at reducing that risk. Only these four risk drivers were analyzed in this way because their compliance is measured as a site-wide average concentration (see Table 4-3). These results were used to compare the site performance over time of the proposed remedial alternatives.

The calculations of the SWAC for the four human health risk driver COCs include the following factors:

1. Incoming solids inputs to the EW
2. Remedial technology for each alternative applied to each portion of the remediation area:
    a. Surface chemistry concentrations post-remedial action at Time 0 in remediated and unremediated areas
    b. Dredge residuals volume and chemistry (at Time 0)
    c. Chemistry associated with deeper sediments subject to mixing
3. Physical mixing assumptions based on the propwash evaluation (see Section 5.3.3)

The box model evaluation calculates the site-wide SWAC at various time intervals by dividing the EW into sub-areas based on remedial technology and mixing depth. SWAC values are calculated for each sub-area and are then averaged (by area) to calculate the site-wide SWAC. This approach accounts for variation across the site based on remedial technology and mixing depth. The site-wide SWAC values are calculated every 5 years; therefore, SWAC values will be estimated for years 0, 5, 10, 15, 20, 25, 30, 35, and 40 post-construction.

The specific steps used to calculate the site-wide SWAC are summarized in this section. A more detailed discussion, including the mathematical basis for the calculations and uncertainty discussion of the site-wide SWAC, is provided in Appendix J.

Step 1: Parse the EW into Sub-Areas

The EW was divided up into sub-areas based on location and extent of proposed remedial technology (as defined by each proposed alternative) and mixing depth assumptions. Figure 5-4 provides a schematic illustrating how the sub-areas were developed.

First, the EW surface area was divided into sub-areas based on location and spatial extent of remedial technologies proposed for each developed alternative (second panel from top in Figure 5-4). These sub-areas were further sub-divided based on the assumed depth of the mixing zone[69] (third panel from top in Figure 5-4). This division results in a series of areas within the EW that have both the same remedy and mixing depth (bottom panel in Figure 5-4).

The surface area for sub-areas that have the same remedy and mixing zone will be added together to create a tabular summary of each alternative discussed in Section 8. These tabular summaries are provided in Appendix J.

Step 2: Define Bed Mixing Models for Each Remedial Technology/Mixing Zone Combination

A bed mixing model was developed for each remedial technology and potential mixing depth (sub-areas developed in Step 1). The bed mixing model defines the vertical layers of sediment at Time 0 (post-construction) for each area considering remedial technology and the vertical extent of the assumed mixing depth. The three vertical sediment layers defined in the bed mixing model include RMC, dredge residuals, and sediment bed remaining after remedial action. A schematic example of the bed mixing model at Time 0 is shown in Figure 5-5 for remediated areas (top panel) and non-remediated areas (bottom panel). Detailed figures of bed mixing models for each proposed remedy and mixing depth combination are provided in Appendix J.

Step 3: Calculate Site-wide SWAC

The upstream and lateral solids loads and chemistry for current and future conditions (Section 5.3.2), table of sub-areas by remedy/mixing zone (Step 1) and the associated bed

[69] Mixing depth assumptions are shown in Figure 5-3, and discussed in Section 5.3.3.

mixing model (Step 2) are used to calculate the site-wide SWAC every 5 years for years 0 through 40 post-construction.

Each remedy/mixing zone sub-area developed in Step 1 is assumed to fully mix during each 5-year time period based on the bed mixing model and mixing depth defined for that sub-area. After mixing occurs, a surface sediment (top 10 cm) concentration is calculated for each remedy/mixing zone sub-area over the defined mixing depth. The site-wide SWAC for the EW is then calculated by averaging these concentration values for each remedy/mixing zone sub-area using Equation 5-1:

$$\frac{\sum_{i=1}^{n} A_i \times C_i}{\sum_{i=1}^{n} A_i} = \text{SWAC (site-wide)} \qquad (5\text{-}1)$$

where:

n	=	Total number of sub-areas
A_i	=	Area of sub-area
C_i	=	Concentration of surface sediments (averaged over the mixing depth) for each sub-area

A detailed description, including mathematical basis, of the site-wide SWAC calculations is provided in Section 2 of Appendix J.

5.3.7 Area-specific SWAC

In addition to the site-wide SWAC; the box model evaluation was used to estimate SWAC values for specific areas to inform the evaluation of alternatives where MNR may be selected as the remedial technology (e.g., underpier areas) and to assess compliance with RAO 2 in clamming areas (see Table 4-3). These calculations were done using the same Steps 1 through 3 discussed in Section 5.3.6, where the total area considered is a specific subsection of the EW site. A detailed description, including mathematical basis, of the site-specific SWAC calculations is provided in Appendix J.

5.3.8 Sensitivity and Bounding Evaluations

To account for variability and uncertainty in the physical processes and sediment/solids chemistry values used in the box model evaluation, and determine their impacts to the evaluation of site performance over time, two analyses were completed as part of the FS: sensitivity and bounding. The purpose of the sensitivity analysis was to evaluate the relative impact of each parameter to the site-wide SWAC value or surface concentrations over time predicted by the evaluation. The bounding analysis was based on the results of the sensitivity evaluation, and was used to bound the range of potential SWAC values based on combinations of parameters that could have the most effect on the predicted SWAC values. These analyses were done using information specific to a proposed remedial alternative to ensure that the response of the SWAC calculations to changes in parameters reflects the complexity of the proposed alternatives; remedial Alternatives 1A(12) and 2B(12) were used (see Sections 8.2.5 and 8.2.8 and Figures 8-2 and 8-5). These alternatives were chosen for the sensitivity analysis because of their differences: Alternative 1A(12) has less removal than Alternative 2B(12) in open-water areas and has MNR proposed in underpier areas, whereas Alternative 2B(12) proposes in situ treatment in underpier areas. Therefore, the effect of the input parameters on the remedial technologies could be explored. See Sections 7 and 8 for a description of the remedial technologies and the alternatives, respectively. The details and results of these evaluations are discussed in Appendix J, including the uncertainty of the estimated SWAC values based on selection of specific calculation parameters.

5.4 Recontamination Potential Evaluation

The potential for the site to recontaminate following remedial actions has also been evaluated as part of the FS. The purpose of the recontamination potential evaluation is to determine if there are discrete areas within the EW where recontamination may be of concern based on deposition from upstream and EW lateral solids. Portions of the EW predicted to exceed the RALs were used as a metric to identify areas where potential recontamination could occur to inform where post-construction monitoring may be needed.

The evaluation of recontamination potential is challenging in the EW due to the influence of anthropogenic activity, such as propwash, which can resuspend recently deposited finer sediments and/or mix them into the underlying sediments. The impacts of anthropogenic activity on the spatial distribution of EW lateral solids deposition was not taken into account with the PTM because of the difficulty in accurately quantifying the location, mass, and frequency of solids resuspended by vessel activity. Therefore, the recontamination evaluation focused on identifying areas of concern using RALs as metrics without attempting to quantify surface concentrations in the long term with certainty.

The recontamination potential evaluation was conducted using the results of numerical modeling (i.e., PTM) as input to a GIS-based mathematical model to identify specific areas within the EW that may have the potential to recontaminate in the future. These areas were further evaluated to determine if predictions are reasonable, whether areas of recontamination have a significant adverse impact on maintaining RAOs, and to help inform and focus long-term monitoring efforts following completion of the remedial actions. This evaluation is referred to as the grid model evaluation.

The initial deposition quantities and patterns of EW lateral solids sources (i.e., CSOs and SDs) within the EW area were determined through use of a PTM. Deposition based on current solids loading was provided in Section 7 of the STER (Anchor QEA and Coast & Harbor Engineering 2012). Additional modeling using the PTM was conducted as part of the FS to evaluate initial deposition of EW lateral inputs once likely future source control measures are employed. Appendix B, Part 1 provides a detailed description of the additional modeling using the PTM for future conditions. An overview of solids input and deposition in the EW is provided in Section 5.1.

For both the current and future PTM outputs, different chemical concentrations were applied to the distribution of solids predicted to be deposited in each PTM grid cell from each lateral solids load and upstream sources (constant throughout the EW) to calculate surface sediment concentrations in the upper 10 cm. The results of both the current and future model outputs were used to identify discrete areas within the EW where recontamination potential could be a concern. The sections below provide an overview of the physical process and chemistry assumptions used in the recontamination potential evaluation, and the methodology used for evaluation.

5.4.1 Review of PTM

The output and post-processing for the PTM is described in detail in Section 7 of the STER (Anchor QEA and Coast & Harbor Engineering 2012) and additional, potential future, conditions were run with the PTM and described in detail in Appendix B, Part 1. However, for the purposes of the FS, a brief review of the output of the PTM is provided to assist with the methodology discussion for the recontamination potential evaluation.

The raw output of the PTM includes particle locations within the EW that represent where solids from various EW lateral sources have deposited in the EW. This is an initial deposition and does not including resuspension and lateral movement after deposition. The locations of all the deposited particles (from all EW lateral solids sources) were extracted from the raw PTM output file and imported into ArcGIS. The points were then post-processed to create a raster representation of mass accumulation in the EW with a 50-foot by 50-foot resolution.[70] Mass accumulation within each 50-foot by 50-foot cell in the raster was calculated by adding all of the particles that had been deposited within that area. This cell size was chosen to provide an appropriate level of resolution for predicting solids deposition patterns within the EW and to assess the recontamination potential within the EW.[71] Figures showing these initial deposition patterns and quantities in the EW for all EW lateral sources are provided in Appendix B, Part 1.

5.4.2 Chemistry Assumptions

Nine COCs were selected for the recontamination potential evaluation. Seven of these are key benthic risk driver COCs (total PCBs, arsenic, mercury, total high-molecular-weight polycyclic aromatic hydrocarbon [HPAHs], total low-molecular-weight polycyclic aromatic hydrocarbons [LPAHs], BEHP, and 1,4-dichlorobenzene), which together serve as a surrogate for the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA (Windward 2012a). Note that total PCBs and arsenic are also human health risk

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[70] Each particle represents 0.5 kg of sediment; see Section 7.3.3 of the STER (Anchor QEA and Coast & Harbor Engineering 2012) for more information.

[71] An evaluation of the influence of cell size on concentrations and deposition patterns predicted by the PTM can be found in Section 7.3.5 of the STER.

drivers. The other two COCs for the recontamination potential evaluation are the remaining human health risk drivers (cPAHs and dioxins/furans).

Chemistry assumptions for upstream sources for the recontamination potential evaluation were developed using the same methodology as used for the box model (see Section 5.3.1). However, chemistry assumptions for EW lateral sources were refined in the PTM analysis compared to box model. The recontamination potential evaluation assigns chemistry based on consideration of individual or similar SD and CSO basin characteristics that could result in more basin-specific chemistry assignments. This is because the PTM is used to evaluate location-specific conditions; whereas the box model, which assigned one chemistry to SDs and one to CSOs, evaluates a site-wide average concentration rather than location-specific conditions. Since the recontamination evaluation calculates surface concentrations based on a model cell-by-cell basis based on initial deposition patterns predicted by the PTM output, it is necessary to break down EW lateral sources into finer resolution for chemistry assumptions. Chemistry assumptions for the recontamination potential evaluation are assigned for current and future source control conditions based on the following six categories:

- Hinds CSO
- Lander CSO
- Hanford #2 CSO
- Nearshore SDs (Port of Seattle, City of Seattle, and private)
- S Lander St SD
- All non-nearshore SDs (e.g., S Hinds St SD, USCG SD, etc.)

Decisions on these refinements considered the current source control chemistry data, number of source control samples, similarities of land uses of the basins, and future source control actions. Appendix B, Part 4 provides a detailed discussion of how chemistry assumptions for EW lateral sources were developed. Tables 5-6 and 5-7 provide chemistry assumptions used for the recontamination potential evaluation for upstream and EW lateral sources for current and future (source control) conditions, respectively.

Table 5-6
Chemistry Assumptions for Upstream and East Waterway Lateral Source Solids for Recontamination Potential Evaluation (Current Conditions)

Inputs	COC								
	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	BEHP (µg/kg dw)	1,4-DCB (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxin/Furan TEQ (ng TEQ/kg dw)
Hinds CSO									
mean[1]	5	1.71	4,000	870	680	6,700	820	260	16
median[2]	6	0.36	2,900	640	430	3,000	260	240	7.6
90th percentile[3]	9	2.57	10,000	1,900	1,500	23,000	2,000	630	37
Lander CSO									
mean[1]	2	0.21	1,800	280	250	1,000	320	11	1.8
median[2]	2	0.25	2,200	220	300	800	230	11	1.8
90th percentile[3]	2	0.26	2,700	500	380	1,700	560	18	2.6
Hanford #2 CSO									
mean[1]	6	2.00	3,900	880	670	7,700	990	270	30
median[2]	6	0.72	3,100	670	540	3,300	320	250	30
90th percentile[3]	9	2.94	6,200	1,600	930	27,000	2,300	510	44
Nearshore SDs[4]									
mean[1]	10	0.09	5,500	1,000	820	8,300	75	160	15
median[2]	10	0.08	4,400	740	550	6,200	17	39	7.9
90th percentile[3]	15	0.14	14,000	1,900	2,100	19,000	180	440	32
S Lander St SD									
mean[1]	9	0.15	14,000	2,600	2,100	12,000	110	120	68
median[2]	10	0.13	5,500	810	670	9,300	90	53	68
90th percentile[3]	20	0.29	17,000	3,400	2,400	21,000	200	280	93
All Non-nearshore SDs[5]									
mean[1]	10	0.19	10,000	2,000	1,400	19,000	140	290	68
median[2]	7	0.12	4,000	680	450	9,400	90	58	68
90th percentile[3]	20	0.32	11,000	3,400	1,700	24,000	280	460	93
LDW Laterals[6]									
base	13	0.14	3,900	880	1,400	15,475	990	300	20
LDW Bed[7]									
base	16	0.53	3,800	700	390	590	23	350	26
Green River									
base	9	0.10	1,300	130	135	120	1.20	42	6
low bounding	7	0.06	160	17	40	75	0.84	5	2
high bounding	10	0.20	1,900	230	270	210	1.30	80	8

Notes:
1. Mean chemistry values are used for Base Case scenarios.
2. Median chemistry values are used for Low Bounding Case scenarios.
3. 90th percentile chemistry values are used for High Bounding Case scenarios.
4. Nearshore SDs include SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along the waterfront (A-6, B-40, B-41, B-42, B-43).
5. Non-nearshore SDs include S Hinds St SD, SW Spokane St EOF/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, BR-39).
6. Values for LDW Laterals are taken from the LDW FS (AECOM 2012) when available.
7. Values for LDW Bed are based on the baseline SWAC when available in the LDW FS (AECOM 2012) (for the four human health risk driver COCs), and are otherwise based on the baseline average of surface sediment samples (for other SMS contaminants).

µg/kg – micrograms per kilogram
1,4-DCB – 1,4-dichlorobenzene
BEHP – bis(2-ethylhexyl) phthalate
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EOF – emergency overflow
FS – Feasibility Study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
ng – nanograms
PCB – polychlorinated biphenyl
SD – storm drain
SMS – Washington State Sediment Management Standards
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent

Table 5-7
Chemistry Assumptions for Upstream and East Waterway Lateral Source Solids for Recontamination Potential Evaluation (Future Conditions)

Inputs	COC								
	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	BEHP (µg/kg dw)	1,4-DCB (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxin/Furan TEQ (ng TEQ/kg dw)
Hinds CSO									
mean[1]	5	1.71	4,000	870	680	6,700	820	260	16
median[2]	6	0.36	2,900	640	430	3,000	260	240	7.6
90th percentile[3]	9	2.57	10,000	1,900	1,500	23,000	2,000	630	37
Lander CSO									
mean[1]	2	0.21	1,800	280	250	1,000	320	11	1.8
median[2]	2	0.25	2,200	220	300	800	230	11	1.8
90th percentile[3]	2	0.26	2,700	500	380	1,700	560	18	2.6
Hanford #2 CSO									
mean[1]	6	2.00	3,900	880	670	7,700	990	270	30
median[2]	6	0.72	3,100	670	540	3,300	320	250	30
90th percentile[3]	9	2.94	6,200	1,600	930	27,000	2,300	510	44
Nearshore SDs[4]									
mean[1]	10	0.09	5,500	1,000	820	8,300	75	160	15
median[2]	10	0.08	4,400	740	550	6,200	17	39	7.9
90th percentile[3]	15	0.14	14,000	1,900	2,100	19,000	180	440	32
S Lander St SD									
mean[1]	9	0.15	**8,600**	**1,600**	2,100	12,000	110	120	**22**
median[2]	10	0.13	5,500	810	670	9,300	90	53	**12**
90th percentile[3]	20	0.29	17,000	3,400	2,400	21,000	200	280	**37**
All Non-nearshore SDs[5]									
mean[1]	**10**	**0.16**	**6,800**	**1,600**	**930**	**14,000**	140	**200**	**22**
median[2]	**7**	0.12	4,000	680	450	9,400	90	58	**12**
90th percentile[3]	**20**	0.32	11,000	3,400	**1,600**	24,000	**260**	460	**37**
LDW Laterals[6]									
base	13	0.14	3,900	880	1,400	15,475	990	300	20
LDW Bed[7]									
base	16	**1**	3,800	700	390	590	23	350	26
Green River									
base	9	0.10	1,300	130	135	120	1.20	42	6
low bounding	7	0.06	160	17	40	75	0.84	5	2
high bounding	10	0.20	1,900	230	270	210	1.30	80	8

Notes:
1. Mean chemistry values are used for Base Case scenarios.
2. Median chemistry values are used for Low Bounding Case scenarios.
3. 90th percentile chemistry values are used for High Bounding Case scenarios.
4. Nearshore SDs include SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along the waterfront (A-6, B-40, B-41, B-42, B-43).
5. Non-nearshore SDs include S Hinds St SD, SW Spokane St EOF/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, BR-39).
6. Values for LDW Laterals are taken from the LDW FS (AECOM 2012).
7. Values for LDW Bed are based on the baseline SWAC when available in the LDW FS (AECOM 2012) (for the four human health risk driver COCs), and are otherwise based on the baseline average of surface sediment samples (for other SMS contaminants).

Values are the same as current conditions shown in Table 5-6 (grey text) except where noted (**bold black text**).

µg/kg – micrograms per kilogram
1,4-DCB – 1,4-dichlorobenzene
BEHP – bis(2-ethylhexyl) phthalate
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EOF – emergency overflow
FS – Feasibility Study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
ng – nanograms
PCB – polychlorinated biphenyl
SD – storm drain
SMS – Washington State Sediment Management Standards
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent

5.4.3 Contribution from Upstream Solids Sources

The average net sedimentation rate assumed for the EW for use in the box model evaluation (see Section 5.1.2), 1.2 cm/yr, was also applied to the entire EW to represent annual net deposition (for current conditions) due to all solids sources identified in Section 5.1.1.

The method used to estimate the contribution of upstream solids sources (for current conditions) to the average net sedimentation rate is different from what was used in the box model evaluation (see Table 5-4). Instead of using the entire EW surface area to estimate a deposition rate in cm/yr from upstream and EW lateral inputs, the smaller surface area where the PTM predicts deposition from EW lateral inputs was used (the shaded areas shown in Figures 7 through 12 in Appendix B, Part 1). This results in a slightly larger contribution from EW lateral inputs (in cm/yr over that smaller area) in those locations compared to how it was depicted in the box model evaluation, where deposition from EW lateral inputs were spread evenly throughout the entire EW area. The contribution from upstream sources for current conditions in those locations is calculated by subtracting the contribution from EW lateral sources from the assumed average net sedimentation rate measured by geochronological cores (1.6 cm/yr, see Section 5.1.2). These calculations are provided in Appendix J.

The solids contribution from upstream sources for future conditions is assumed to remain the same as current conditions (see Appendix J). This is because the majority of the upstream solids are from the Green River and there is no information available to suggest changes in the solids load from the Green River in the future. The contribution of EW lateral solids sources for likely future conditions were estimated using the updated PTM simulations with likely future source control measures applied to EW lateral solids loads. Annual deposition from EW laterals solids for future conditions is less than current conditions for some discharges due to proposed source control measures, which reduce the amount of sediment coming in from some lateral sources (see Appendix B, Part 1). Since the predicted contribution to total annual deposition in the EW from EW laterals for future conditions is decreased, and the upstream contribution is assumed to be the same as current conditions, predicted total deposition from all sources for future conditions is slightly less than current conditions.[72]

5.4.4 Vertical Mixing Assumptions

The vertical mixing assumptions used for the recontamination evaluation are constant throughout the EW and equal to a bioturbation depth of 10 cm (depth of the BAZ as determined in the EW SRI; Windward and Anchor QEA 2014). Vertical mixing due to propwash is not considered when evaluating recontamination potential. These assumptions result in conservatively high estimates of surface concentrations in areas where the deposition from EW lateral sources is predicted to be high.

5.4.5 Spatial Distribution of Surface Concentrations in the East Waterway

The results of the current and future conditions (after future source control is implemented) deposition from EW lateral sources (see Section 5.4.1), chemistry assumptions (Section 5.4.2), contribution of upstream sources to the EW (Section 5.4.3), and vertical mixing assumptions (Section 5.4.4), were used to determine if there are any discrete areas within the EW that have the potential to recontaminate following remediation.

This evaluation was accomplished by calculating surface concentrations within each 50-foot by 50-foot PTM grid cell (cell).[73] The information required in each cell is listed below:

- The underlying surface concentrations throughout the EW at Time 0 (post-construction) for each COC were assumed to be zero. This assumption was made to focus the evaluation on recontamination potential due to incoming solids.
- Initial deposition from EW lateral solids sources from PTM results (with and without future source control actions).

[72] Total predicted deposition from all sources for current conditions was taken from the assumed average net sedimentation rate for the EW measured by geochronological cores (see Section 5.1.2).

[73] Surface concentrations will be calculated using dry weight concentrations for all nine key risk driver COCs and will also be calculated as carbon-normalized concentrations for total PCB, HPAH, LPAH, 1,4-dichlorobenzene, and BEHP for comparison to benthic community PRGs.

- EW lateral solids chemical concentrations for nine key risk driver COCs (including both human health and ecological)[74] for existing and future conditions (Section 5.4.2 and Tables 5-6 and 5-7).
- Contribution of upstream sediment solids sources to assumed average total net sedimentation rate (see Section 5.4.3).
- Upstream solids chemical concentrations for the nine key risk driver COCs being evaluated (Tables 5-6 and 5-7).
- Mixing depths (set to 10 cm due to bioturbation for all cells).

Surface concentrations within each cell will be calculated in four steps described below:

1. The upstream contribution (in kg/yr) is a constant value for each cell and is set to a value estimated as described in Section 5.4.3. A chemical concentration (in mass per kg of solids) for the nine key risk driver COCs being evaluated are associated with the upstream contribution of solids in each cell (these values are the same for current and future conditions).
2. The underlying location specific surface sediment chemical concentrations in each cell were set to zero for all COCs and proposed alternatives (see Appendix J).
3. The PTM output (for both current and future/source control conditions) provides deposition (in kg/yr) of EW lateral solids sources in each cell. A chemical concentration (in mass per kg of solids) for the nine key risk driver COCs being evaluated are associated with the EW lateral solids in each cell (for both current and future/source control conditions, based on the six categories of EW lateral sources outlined in Section 5.4.2).
4. The depositional solids concentrations in each cell (due to upstream and EW lateral solids contributions) is mixed (based on the 10-cm bioturbation thickness) with the underlying sediment chemical concentrations to establish surface concentrations annually for years 1 to 30 post-construction.

[74] All nine risk driver COCs are evaluated for recontamination potential, but only those identified as risk driver COCs for the benthic community will be evaluated in the site performance over time evaluation; the box model evaluation is used for the site performance over time evaluation for the other RAOs (human health and other ecological receptors).

The output of the evaluation includes maps summarizing areas in the EW that exceeds RALs and CSLs for years 5, 10, 15, and 30 years post-construction. The resolution of the maps is the same as the predicted EW lateral deposition maps developed from the PTM results (see Figure 2-14), which is 50 feet by 50 feet. This information was used to evaluate localized recontamination potential for discrete areas in the EW.

5.4.6 Sensitivity Analyses

The sensitivity of predicted surface concentrations in each cell due to uncertainty in the model inputs (both solids load and assumed chemistry) was evaluated through development of upper and lower bound scenarios. These scenarios are a combination of a low- and high-level estimate of both solids input and chemistry assumptions. Low solids loads were paired with low chemistry assumptions, and likewise with mid- and high-level estimates for solids and chemistry to properly bound the results of the evaluation. The list of sensitivity and bounding scenarios and discussion of the analysis for the recontamination potential evaluation is provided and discussed in Appendix J. An uncertainty discussion for this evaluation is discussed in detail in Appendix J and summarized in Section 5.6.3 herein.

5.5 Point Mixing Model for Evaluation of RAO 3

The box model evaluation described above was used to estimate site-wide and area-specific SWACs for alternatives to assess compliance with RAOs 1, 2, and 4, which are evaluated based on area-average concentrations. RAO 3, however, is assessed based on individual point locations as opposed to area averages. Therefore, an additional calculation, referred to as the point mixing model evaluation, was conducted for seven key benthic risk drivers to predict compliance with RAO 3. These seven key benthic risk drivers serve as surrogates for the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA (Windward 2012a) and include total PCBs, arsenic, mercury, total HPAHs, total LPAHs, BEHP, and 1,4-dichlorobenzene. The point mixing model uses similar assumptions as the box model evaluation to predict surface sediment concentrations for years 0 through 40 post-construction for 18 point locations (baseline surface sediment stations) in proposed MNR areas that exceed the RAO 3 PRGs. This analysis was limited to these point locations because other locations are expected to meet RAO 3 PRGs following construction (either through active remediation, such as dredging, or because they are below RAO 3 PRGs currently). As discussed in Section 9, evaluation of RAO 3 is based on all sample locations (342) throughout the EW. This point mixing model is used to predict the outcome of 18 locations planned for MNR (in underpier and under bridge areas). All other locations are expected to meet RAO 3 PRGs following construction, either through active remediation because they are above RALs, or because they are below RAO 3 RALs/PRGs currently. This evaluation is also discussed in Section 9.2.2 of the FS.

This evaluation uses the similar methodology for calculating surface concentrations as the box model; however, instead of calculating area-wide average concentrations, concentrations are estimated at 18 discrete sample locations in underpier and under-bridge areas (Figure 5-6) where MNR is being proposed in select remedial alternatives. Assumptions for deposited solids and mixing used for this evaluation are summarized below:

- Year 0 surface chemistry at each of these points is based on baseline surface sediment concentrations (i.e., samples taken at these locations between 2001 and 2009).
- EW lateral solids deposition at each point predicted by the PTM results in the model cell that point falls within. Therefore, deposition from EW laterals sources varies across the 18 point locations.
- Upstream solids deposition rate is assumed to be constant across the EW; values are the same as those used for the recontamination potential evaluation (Appendix J).
- Chemistry assumptions for EW lateral and upstream sources are the same as those assumed for the recontamination evaluation (Tables 5-6 and 5-7).
- Mixing assumptions (depths and timeframes for mixing to occur) are the same as the box model evaluation (see Section 5.3.3).

Surface concentrations at each point were predicted for years 5 through 40 (at 5-year intervals), and results were compared to RALs and SMS marine benthic CSLs. The results of the evaluation are provided in Section 9. A detailed description of the calculations, including mathematical basis, is provided in Appendix J.

The sensitivity of predicted surface concentrations at each point to various parameter assumptions is discussed in Appendix J, but is assumed to be similar to the sensitivity of the surface concentrations (SWAC values) calculated in the box model evaluation.

5.6 Uncertainty Discussions

Uncertainty of input variables and calculation methodology for the evaluation of site performance over time (box model evaluation and point mixing model) and recontamination potential was assessed based on sensitivity and bounding evaluations, which are discussed in detail in Appendix J and summarized below. Overall, the predictive model performed as expected when varying input parameters, and the overall uncertainty of the model predictions is acceptable for use in comparison of alternatives within the framework of the FS.

5.6.1 Uncertainty Associated with Input Values

There are numerous uncertainties associated with methods used to determine input values for the predictive modeling analysis summarized in this section. These uncertainties are documented in detail in previous finalized documents. Uncertainty associated with the EW STE, such as measured values of net sedimentation rates from recovered geochronology core data collection and laboratory analyses, predicted initial deposition from EW lateral inputs by the PTM, and shear stresses calculated from vessel operations are discussed in detail in Sections 3.4, 6.3.1, and 7.3.7 in the STER (Anchor QEA and Coast & Harbor Engineering 2012). Discussions of uncertainties in chemistry assumptions used as input for the evaluations are discussed in Appendix B, Parts 3B and 4.

5.6.2 Box Model and Point Mixing Model Evaluation

Section 2.4 in Appendix J provides detail on the sensitivity and bounding analysis for the box model evaluation. Based on the results of the bounding analysis, site-wide SWAC values can vary up to +125% at year 10 and by up to +100% at year 30 due primarily to uncertainty in Green River inputs (solids loading and chemistry assumptions) and net sedimentation rates. When the Green River input and net sedimentation rates are held at the base case assumption, and the other variables (i.e. residuals thickness, percent exchange) are varied within their accepted high and low ranges, SWAC values can vary up to +50% at year 10 and by up to +20% at year 30.

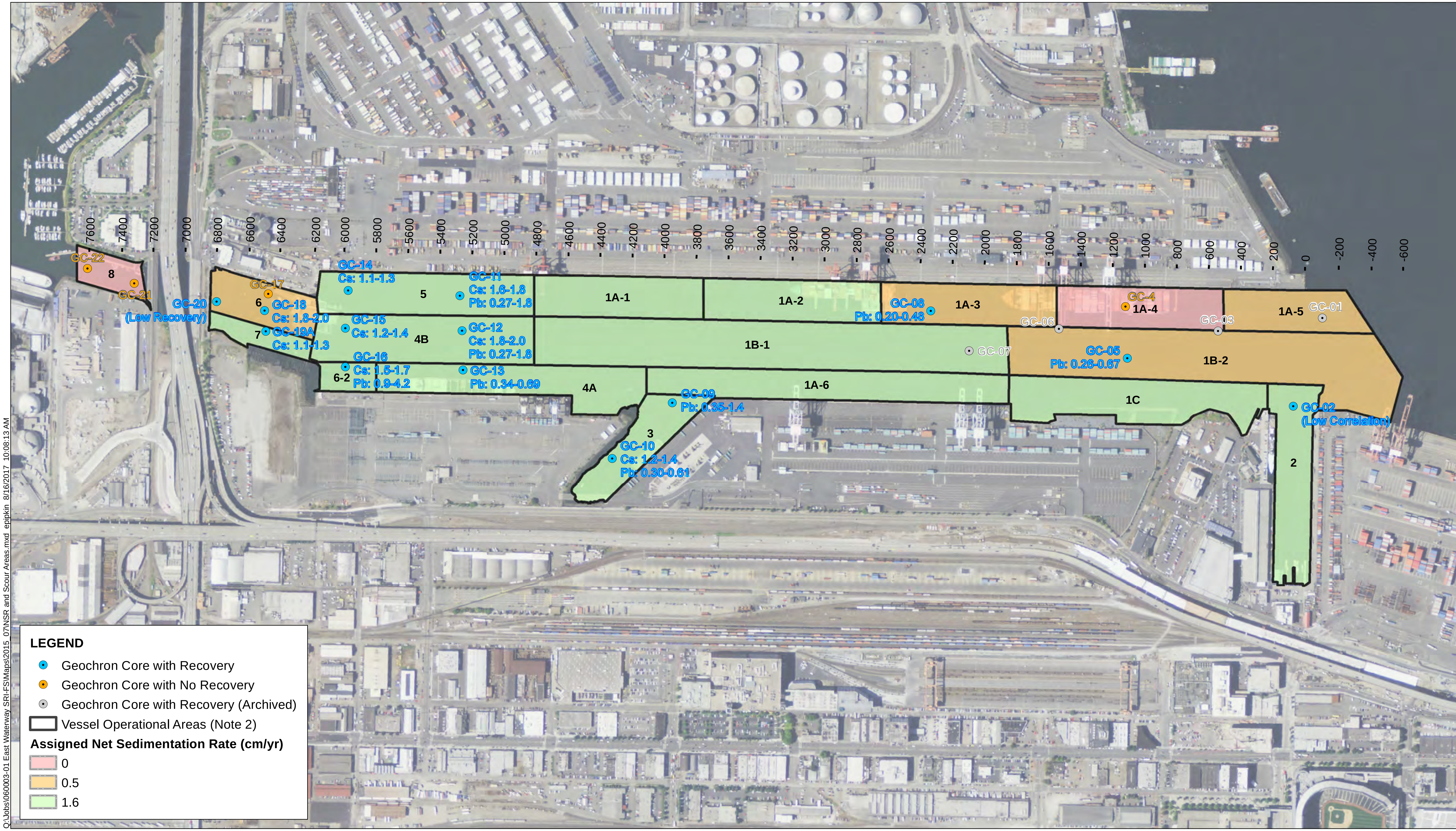
The sensitivity analysis was conducted for two proposed alternatives (Alternatives 1A(12) and 2B(12)[75]) to determine if the uncertainty in the predicted SWAC values is substantially different between alternatives. Detailed discussion of this analysis is located in Sections 2.4.2.1 and 2.4.2.2 of Appendix J. In summary, while the sensitivity of the predicted SWAC calculations to individual parameters differed somewhat between the two alternatives, the range in predicted SWAC values based on the full range of uncertainty in the input parameters was similar for both alternatives. Therefore, while the range of uncertainty in predicted SWAC values is broad based on the uncertainty in the input parameters for the analysis, the box model evaluation is appropriate for comparison of alternatives within the framework of the FS.

The point mixing model evaluation uses the same mathematical model as the box model evaluation. Uncertainties in the predicted surface concentrations for proposed MNR areas calculated with the point mixing model are, therefore, in line with the uncertainties provided for the box model evaluation described in the previous paragraph.

5.6.3 Recontamination Potential Evaluation

A bounding analysis was conducted to estimate uncertainty in predictions of recontamination potential (see Section 4.5 of Appendix J). The results of the bounding evaluation suggest that predictions of the areas of potential recontamination are reduced when inputs are reduced and increase when inputs are increased, as anticipated. However, for all bounding scenarios, areas of concern represent a small portion of the EW area and do not extend far from source outfalls.

[75] See Sections 8.2.5 and 8.2.8 and Figures 8-2 and 8-5 for a detailed description of Alternatives 1A(12) and 2B(12).

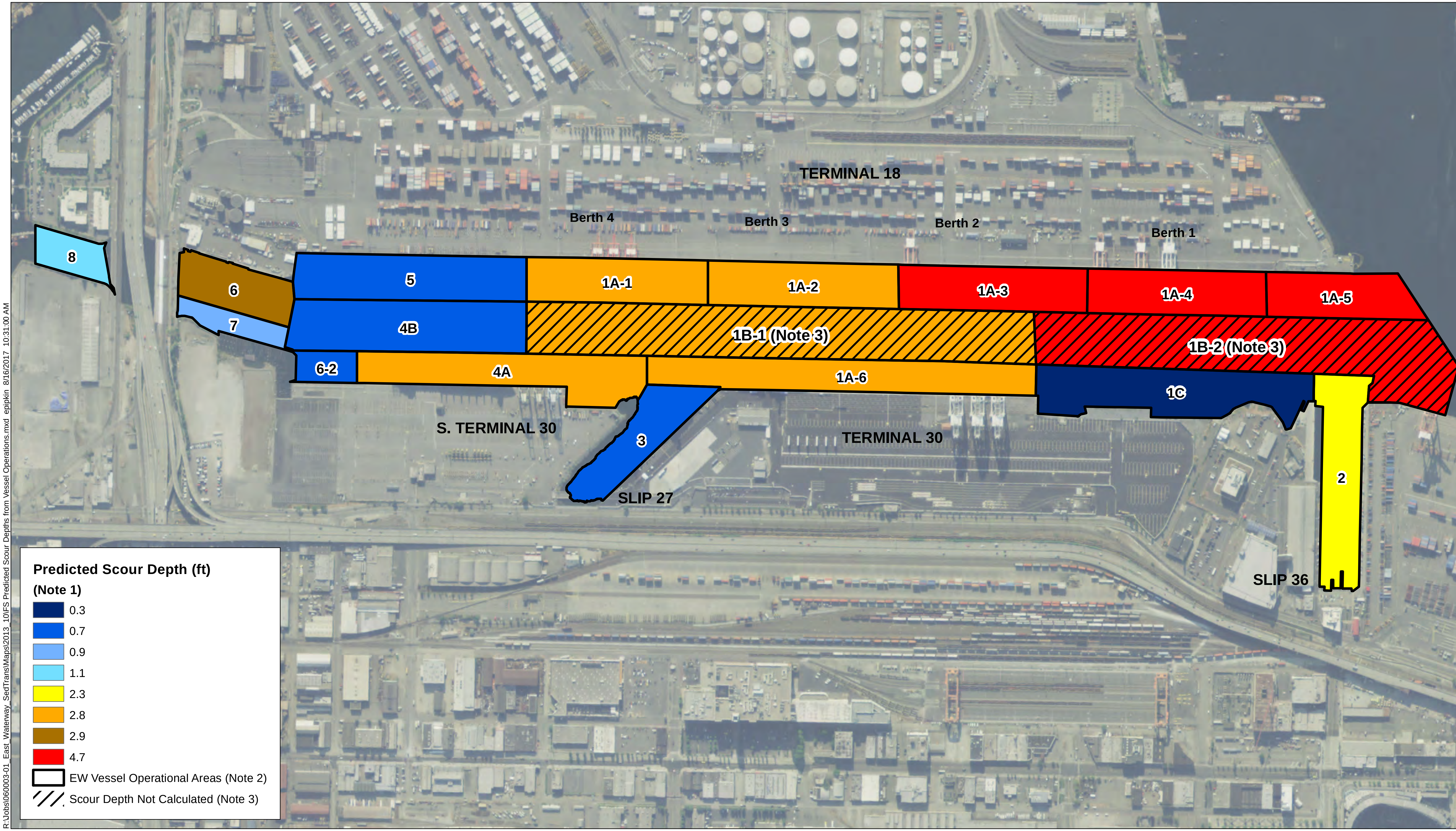


Q:\Jobs\060003-01 East Waterway SRI-FS\Maps\2015_07\NSR and Scour Areas.mxd epipkin 8/16/2017 10:08:13 AM

NOTES:
1. Vertical datum is MLLW, feet.
2. EW Vessel Operational Areas developed as part of the EW STER (Anchor QEA and Coast and Harbor Engineering, 2012); see Section 5.1.2 of the STER.
3. Cores collected in February 2010. Net sedimentation rates in cm/yr.

Feet
0 300 600 900 1,200

Figure 5-1
Geochronology Core Locations, Vessel Operations and Net Sedimentation Areas
Feasibility Study
East Waterway Study Area



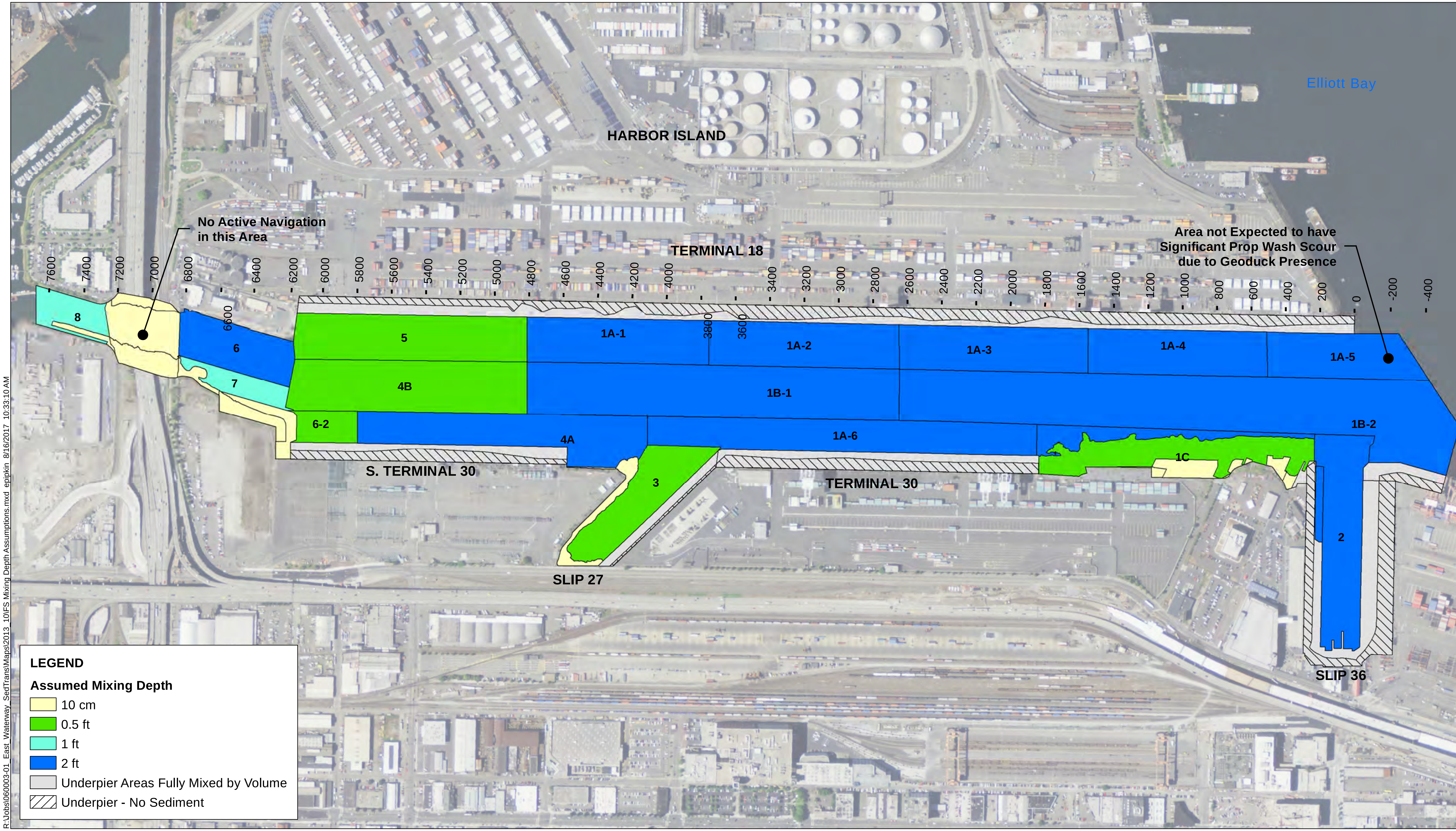
R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_10\FS Predicted Scour Depths from Vessel Operations.mxd epipkin 8/16/2017 10:31:00 AM

NOTES:

1. Calculations for scour depths provided in Appendix B, Part 2: Scour Depth Analysis Memorandum.
2. EW Vessel Operational Areas developed as part of the EW STER (Anchor QEA and Coast and Harbor Engineering, 2012); see Section 5.1.2 of the STER.
3. Areas 1B-1 and 1B-2 represent the navigation area between Terminal 18 and 30 berthing areas. Since berthing manuevers may begin within the navigation channel depending on weather or other site conditions, this area is expected to experience similar scour depths as the berthing areas.

Feet
0 250 500 750 1,000

Figure 5-2
Predicted Scour Depths from Vessel Operations
Feasibility Study
East Waterway Study Area



R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_10\FS Mixing Depth Assumptions.mxd epipkin 8/16/2017 10:33:10 AM

NOTE:
1. Aerial photo is NAIP, 2011.

Feet
0 250 500 750 1,000

Figure 5-3
Mixing Depth Assumptions
Feasibility Study
East Waterway Study Area

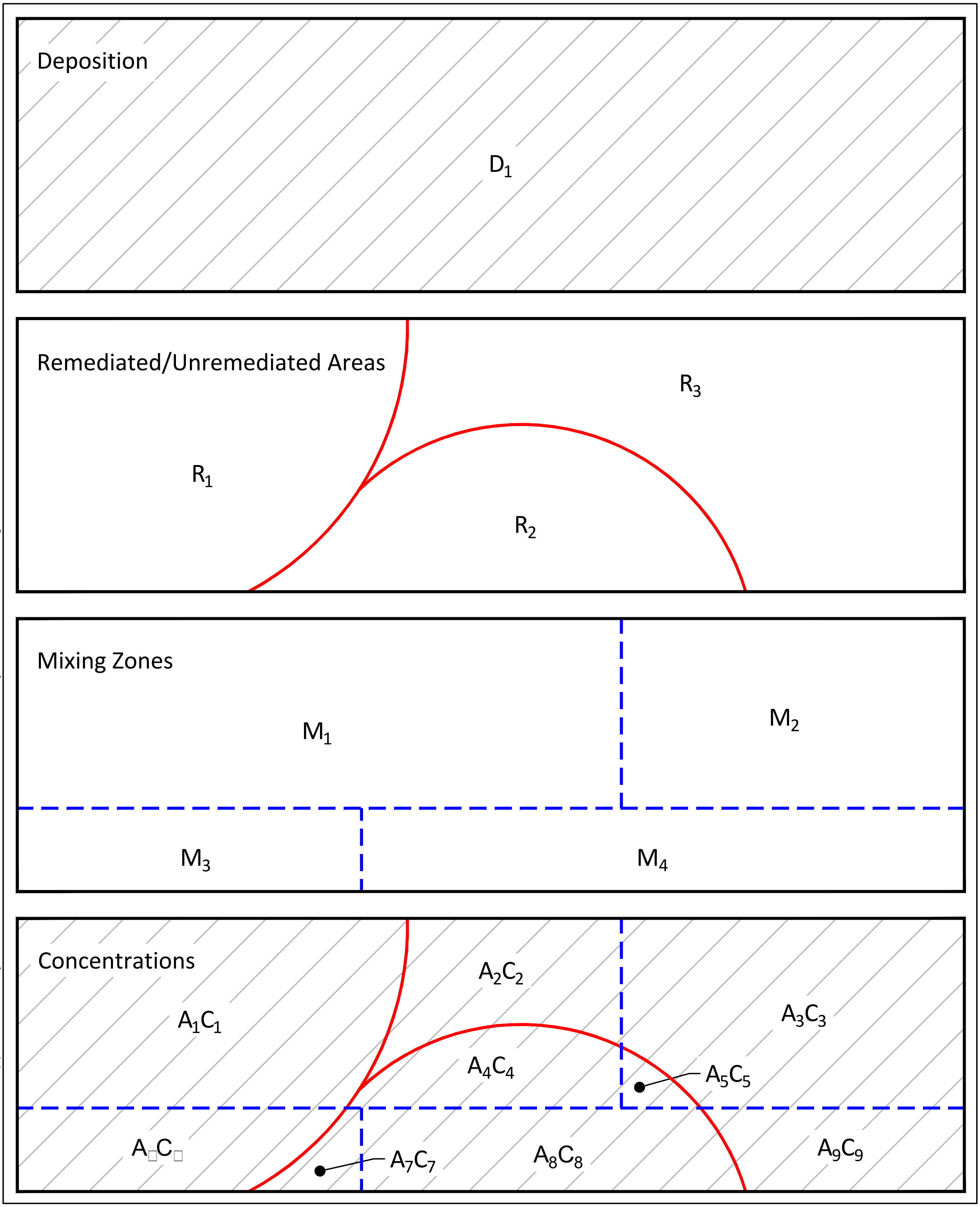


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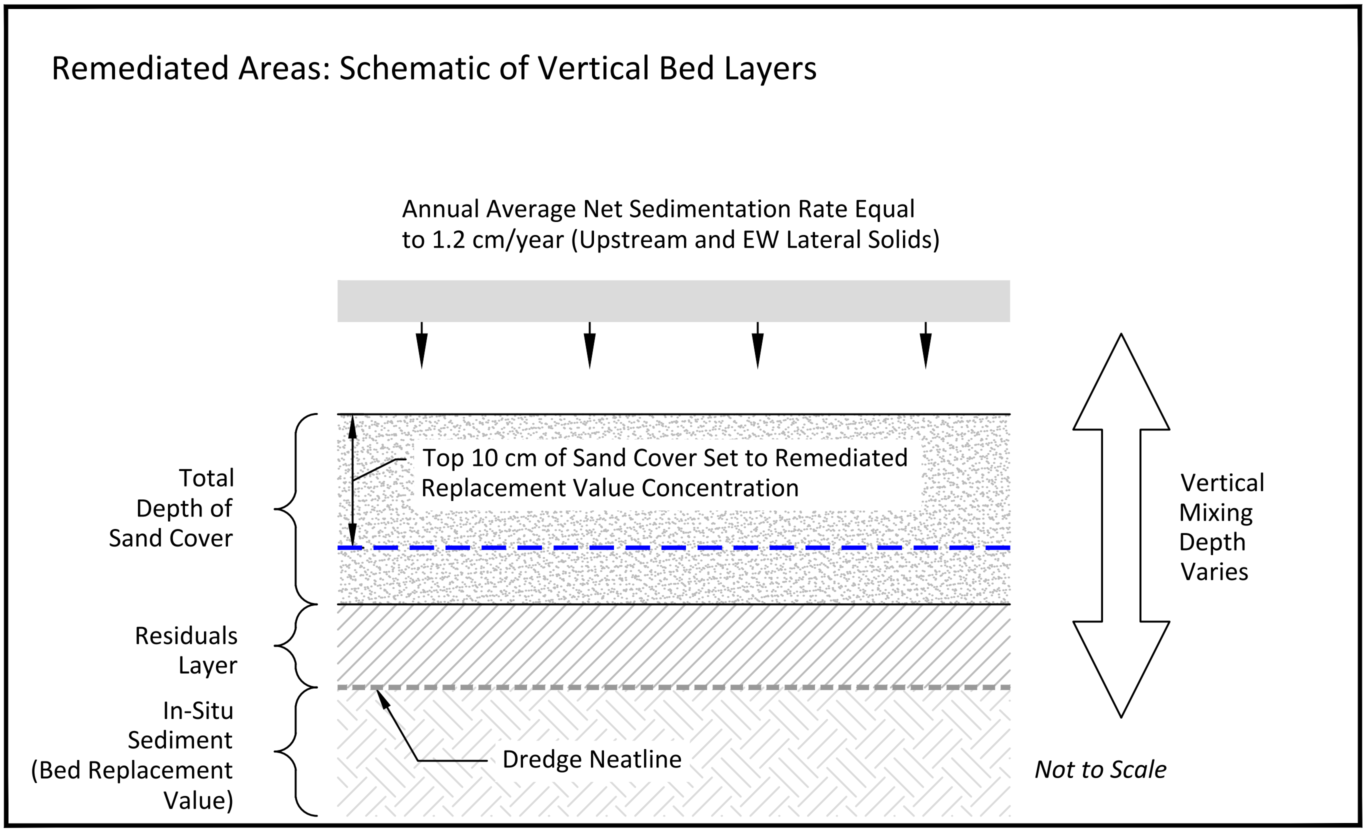
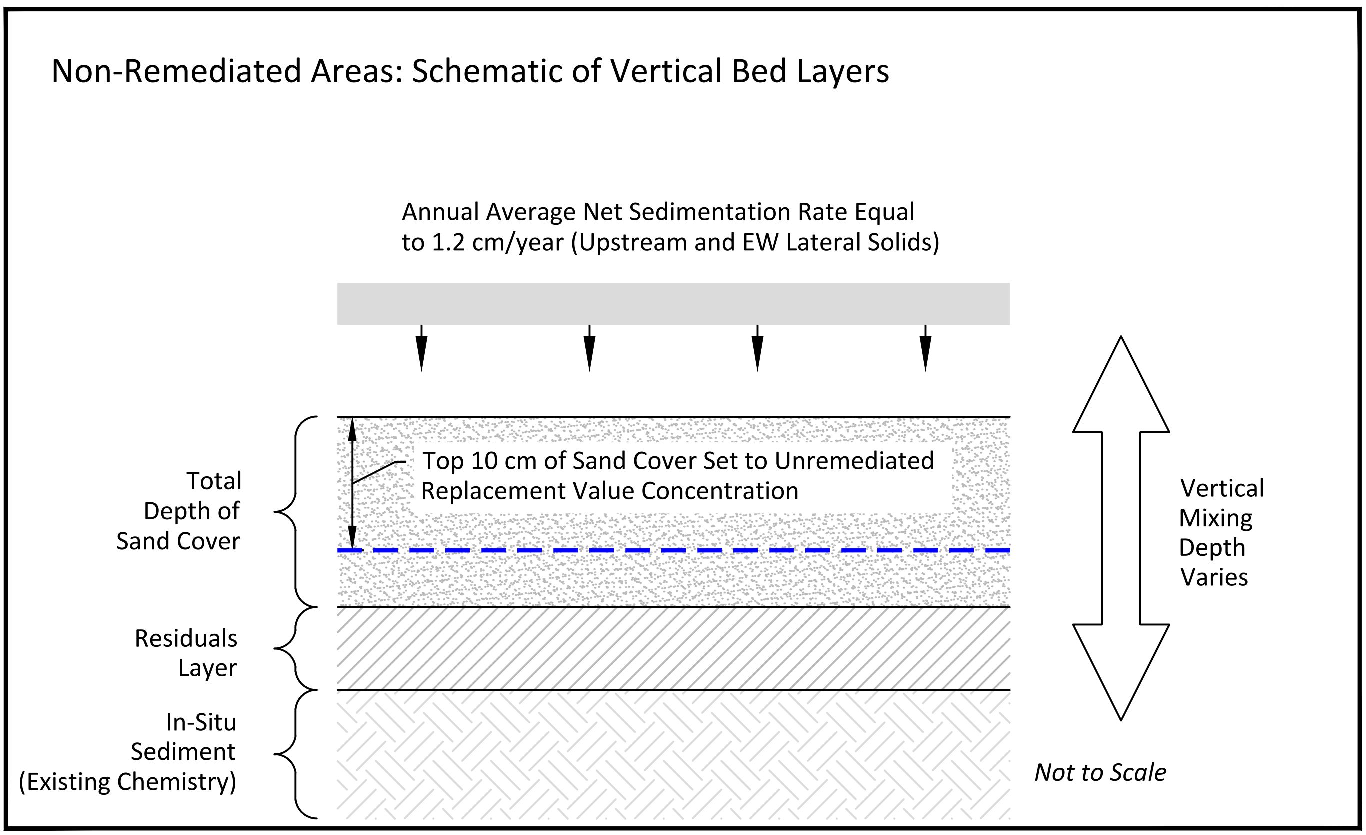
Figure 5-4
Conceptual Overview of Long-Term SWAC Calculation: Box Model Evaluation
Feasibility Study
East Waterway Study Area





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NOTE: The conceptual examples above apply to locations in and near removal areas.
See Appendix J Figures 1a through 1j for additional location-specific conceptual cross-sections.

Figure 5-5
Conceptual Example of Bed Mixing Model Layers
Feasibility Study
East Waterway Study Area

NOTES:

1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2011.

Point Mixing Model Sample Location

Outfall Locations (within PTM Model)

0 500 1,000

Scale in Feet

Figure 5-6
Point Mixing Model Sample Locations
Feasibility Study
East Waterway Study Area

6 REMEDIAL ACTION LEVELS

This section defines the RALs and associated sediment areas of the EW OU requiring remediation. Some shoreline areas within the OU do not contain sediment, but are riprap slopes, as indicated in Figures 6-1 through 6-7. Only areas with sediment will be used to define the area requiring remediation (remediation area), for which remedial alternatives will be developed and evaluated. Consistent with EPA guidance (1988, 2005), delineation of the areas requiring remediation is based on findings of unacceptable risks in the ERA and HHRA (Windward 2012a, 2012b), site conditions, and technical practicability. The methods used to develop the RALs are described in Section 6.1; the rationale for the selection of the RALs is presented Section 6.2; and the RALs are summarized in Section 6.3.

RALs are contaminant-specific sediment concentrations that trigger the need for remediation (e.g., dredging, capping, or MNR). The RALs are designed to achieve RAOs. The RAOs (Section 4) can be achieved through combinations of remediation, natural recovery, and institutional controls. The areas requiring remediation will be refined during remedial design.

PRGs are the long-term cleanup goals for the project, whereas RALs are point-based values that define where remediation is to occur for a given remedial alternative. PRGs are the same for all alternatives. Three sets of RALs are evaluated for screening of alternatives (Appendix L), and two sets of RALs are retained for the detailed development and comparison of alternatives in the FS. RALs will also be used as the performance compliance criteria to verify that remediation for an area is complete, or successful, before equipment is demobilized from an area.

For this FS, RALs are developed for three of four human health risk drivers (total PCBs, arsenic, and dioxins/furans and excluding cPAHs [see Section 3.3.4]) as well as a subset of the ecological risk drivers,[76] which include TBT and a set of indicator SMS chemicals (i.e., selected risk driver contaminants detected above the SQS in surface sediments that represent the extent of SQS exceedances). RALs and associated remediation areas for these risk drivers are designed to address all COCs.

[76] Total PCBs were also identified as an ecological risk driver for fish (RAO 4). The total PCB PRG for human health is lower than the fish PRG, so the remediation area developed in consideration of human health will address risks for fish.

6.1 Methods Used for Development of RALs

This section briefly summarizes the methods used to develop the RALs that serve to define the area requiring remediation (i.e., the remedial footprint) and a corresponding range of expected outcomes based on the range of remedial alternatives (Section 8). The RALs for this FS were selected based on the following considerations:

- Certain sediment PRGs can directly translate into RALs, such as SMS benthic numerical criteria and the TBT RBTC applied on a point basis, which directly relate to protection of the benthic invertebrate community (RAO 3). Compliance with these PRGs is on a point basis.
- Certain PRGs—such as those for total PCBs, arsenic, and dioxins/furans—cannot be used directly as RALs because they are based on area-wide or site-wide average concentrations rather than being point-based (e.g., PRGs based on seafood consumption for RAO 1, or direct contact related to tribal netfishing for RAO 2). In these cases, RALs are developed to meet the site-wide or area-wide (i.e., clamming area) PRGs. Compliance with these PRGs is on an area-wide basis.[77]
- The PRGs for RAO 1 for PCBs and dioxins/furans are based on natural background concentrations. However, as presented in Appendix A, it may not be technically possible to achieve the PRGs for these two risk drivers for the following reasons:
  - The concentrations of these risk drivers from incoming Green/Duwamish River loadings and resuspended sediment in the LDW from scour events are predicted to be higher than natural background.
  - There are practical limitations on control of loadings from lateral sources (i.e., SDs and CSOs) from the LDW and EW drainage basins. Even with large investments in stormwater infrastructure, stormwater generated from urban areas during storm events will release some suspended solids to surface waters. These suspended solids are currently and will continue to be higher than natural background.

[77] While the FS uses model-generated SWACs for area-wide applied PRGs, compliance post-remediation will be determined based on the results of statistical comparisons to ROD-established cleanup levels (e.g., computing UCL95 with post-remediation site sediment data).

- There are constructability constraints within the EW (e.g., overwater structures and bridges; Appendix A), which affects the concentrations that can be achieved following cleanup.

The approach to selecting RALs to achieve RAO 1 is discussed in Section 6.2.2.

6.1.1 Data Used for Selection of RALs and Delineation of Remediation Footprints

The RALs are based on the types and levels of estimated risks in the EW (see Section 3), the RAOs to address those risks and associated PRGs (see Section 4), and the CSM, site conditions, and site data collection and analysis efforts (see Section 2).

The SRI/FS dataset for both surface and subsurface sediments provides a characterization of sediment contamination patterns within the EW. The data used to establish the area requiring remediation consist of detected concentrations of risk driver contaminants in surface sediment (0 to 10 cm) in the entire EW OU. In addition, north of the Spokane Street Bridge, the top 2 feet of sediment were also included because of the potential for propwash to expose this shallow subsurface sediment. These propwash forces do not occur under and south of the Spokane Street Bridge. Typically, data from the top 10 cm are used to delineate the areas requiring remediation since that is the biologically active zone and is the depth that human and other ecological receptors are likely to be exposed. However, since the EW OU is prone to deeper surficial mixing from vessel activity (as described in Section 5), the top 2 feet was also included in the evaluation. During design, it is anticipated that newly collected sediment samples will be used to refine the area above RALs.

6.1.2 Data Mapping and Interpolation Methods

6.1.2.1 Site-wide

The areas requiring remediation for each of the risk drivers were developed using Thiessen polygons, which are used to estimate the distribution of contaminant concentrations. Thiessen polygons were generated using risk driver concentrations in surface sediment throughout the entire OU and shallow subsurface sediment (0 to 2 feet) north of the Spokane Street Bridge.

A Thiessen polygon refers to the boundary of the area that surrounds a unique data point. Thiessen polygons are a commonly used method for characterizing the distribution of sediment chemical contamination and biological effects by assigning chemical concentrations or other values to areas where no actual data exist (i.e., un-sampled areas). Thiessen polygons have boundaries that define the area that is closest to each point relative to all other points. The polygon size and shape is determined by the proximity of neighboring sample locations. The concentration within the entire polygon is assumed to be equal to the concentration of the sample point located at the centroid. Thus, every un-sampled area is assigned the value of its nearest measurement point.

In using Thiessen polygons, each sample point concentration is assumed to contribute to the area-wide mean concentration according to the relative size of the polygon area it represents. Interpolation using Thiessen polygons is a reasonably unbiased method when the distance between sample points is relatively small, because accuracy depends largely on sampling density. However, when sampling locations are spaced several hundred feet apart, the uncertainty in this assumption increases (as with any interpolation method). Areas of dense sampling are characterized by relatively small polygons, whereas areas of sparse sampling are characterized by relatively large polygons.

Thiessen polygons were determined to be an appropriate interpolation method to evaluate the extent of COC concentrations throughout the entire OU due to the high density of data points with good spatial distribution. Additional details on the evaluation and sensitivity of interpolation methods are presented in Appendix C. During design, remediation areas will be further refined (e.g., edges or borders of areas delineated for remediation in the FS), and final areas and volumes requiring remediation will be refined as a result.

Development of the area requiring remediation was based on a stepwise process using both the surface (0 to 10 cm) and shallow subsurface (0 to 2 feet) sediment concentrations. First, surface (0 to 10 cm) sediment sample locations were used to develop Thiessen polygons throughout the entire OU. These Thiessen polygons were compared to SMS criteria for each risk driver using the combined chemistry and toxicity test results. However, samples above SMS criteria (SQS or CSL) for total PCBs were considered to be above SMS criteria regardless of the toxicity test result (which typically would have priority over the chemical results) because PCBs are also a human health risk driver with a PRG for the protection of human health that is lower than the benthic PRG (i.e., SQS).[78] Then, sample locations with subsurface sediment (0 to 2 feet) were added,[79] and new Thiessen polygons were generated in the entire OU. Each of these polygons above SMS criteria were added to the area requiring remediation. As such, if the surface sediment or shallow subsurface sediment (0 to 2 feet) had concentrations above a RAL, the area was included in the remediation area (i.e., either the surface or shallow subsurface could specify the area for remediation). For example, if the shallow subsurface sediment (0 to 2 feet) had concentrations below that RAL, but the surface sediment (0 to 10 cm) had concentrations above the RAL, then the area was designated a remediation area.

As noted in Appendix H, Section 2, cores that were sampled in intervals larger than the upper 2 feet of sediment were not used for establishing remediation areas. For example, if a core had a sample interval of 0 to 3 feet, it was not used to determine if remediation is necessary at that location because the contamination could have been deeper than 2 feet. Instead, all other nearby surface sediment and shallow subsurface cores with an upper interval of 2 feet or less were used. Most of the cores with upper intervals larger than 2 feet are located in the Shallow Main Body Reach, where the mixing depth from propwash is estimated to be 0.7 foot, suggesting contamination present below that depth is unlikely to be exposed due to propwash. The remediation footprint will be refined in design.

6.1.2.2 Intertidal Areas

The extent of the intertidal areas that could potentially be subject to clamming activities include exposed areas without overwater dock structures that contain at least some exposed sediment (and are not entirely riprap shoreline areas). Currently, 1.4 acres contains exposed sediment where clamming could occur. However, potential clamming areas could be expanded depending on future use, as discussed in Section 2.9.4. Therefore, an expanded area

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[78] Total PCBs were also identified as an ecological risk driver for fish (RAO 4). The total PCB PRG for human health is lower than the fish PRG, so the remediation area developed in consideration of human health will address risks for fish.

[79] This includes results collected following completion of Phase 1 dredging but prior to placement of the residuals management sand cover layer.

comprising a total of approximately 4 acres (see Figure 2-11) will be referred to as potential exposed intertidal clamming areas, which will be used for evaluation of RAO 2, the human health direct contact tribal clamming exposure scenario. Other intertidal areas that are entirely riprap (i.e., riprap not overlain by sediment) or are not exposed because they are beneath an overwater apron or pier are not included in the intertidal area evaluated for RAO 2 (see Figure 2-11).

For the potential exposed intertidal clamming areas, arsenic concentrations (the risk driver COC for RAO 2) was estimated for individual intertidal polygons using the available data considered most representative of arsenic concentrations in these areas. Intertidal polygons were developed based on the locations of the 15 intertidal beach composite samples (Figure 6-5). The exposed intertidal area in the entire waterway was divided into individual polygons, with one polygon representing each area where intertidal composite samples were collected. These polygons are more representative than polygons based on subtidal samples in this area since intertidal composite samples were collected specifically to represent the SWAC for the area sampled to estimate potential direct contact exposure. One additional polygon was added adjacent to the southern opening of Slip 36 where additional exposed intertidal habitat is present (but no intertidal composite samples were collected; see inset on Figure 6-5).

Arsenic concentrations were estimated for each intertidal polygon based on the weighted average of intertidal and subtidal sample-derived Thiessen polygons that extend into the accessible intertidal area (presented in Section 6.2.3).

6.1.3 Uncertainty Analysis

This section examines potential uncertainties in the dataset used for establishing the horizontal extent of remediation using the criteria discussed in Sections 6.1 and 6.2. The primary factors contributing to uncertainty are the age of the data and data mapping and interpolation. Overall, the nature and extent of risk driver chemicals are sufficiently understood to characterize risks and develop reasonable estimates of the areas requiring remediation, and identifying the site-wide remedial alternatives for the FS. Refinement of sediment contamination above selected RALs will be based on additional data collection during remedial design, thereby reducing associated uncertainties.

6.1.3.1 Age of Data

The surface and shallow subsurface (0 to 2 feet) sediment data were used to map the area requiring remediation. One rule used to define the SRI/FS baseline dataset is the replacement of older data at stations that were resampled (defined as falling within 10 feet of newer data). This evaluation was conducted on a chemical-by-chemical basis at each older station within 10 feet of a newer station. The intent of this effort was to use the most recent data available for defining the nature and extent of chemical contamination. However, because not all of the older data were co-located with newer data, the FS baseline dataset comprises surface sediment samples spanning 15 years of data collection efforts (1995 to 2010) and subsurface samples spanning 19 years of data collection efforts (1991 to 2010). While it is possible that surface and shallow subsurface conditions have changed in these sampled areas, most of this data collection has occurred in the recent past. More than 80% of the surface and subsurface data has been collected within the last 10 years, thus reducing the uncertainty.

The FS accepts this level of uncertainty by assuming that all data represent current conditions. Remedial alternatives are assembled based on these data along with other lines of evidence described in Section 8. However, sampling conducted during remedial design will reduce this uncertainty.

6.1.3.2 Data Mapping and Interpolation

The SRI/FS baseline dataset contains data from numerous site investigations compiled together to determine the nature and extent of sediment contamination associated with past chemical releases. This extensive dataset was used to build the CSM, map the nature and extent of contamination, and understand site processes for evaluating remedial alternatives. However, as with every environmental investigation, some uncertainty remains associated with the horizontal and vertical extent of sediment contamination, as discussed in the following points:

- **Laboratory Reporting Limits:** A portion of the uncertainty is related to reporting limits for non-detects that exceed the screening criteria, RALs, or the PRGs, especially in older data. Therefore, the area requiring remediation was delineated using only detected SQS exceedance concentrations in the point data (expressed spatially as Thiessen polygons). However, this uncertainty is relatively minor, as described in the uncertainty section of the ERA (Windward 2012a) and Section 4 of the SRI (Windward and Anchor QEA 2014), in which nine contaminants had RLs exceeding the SQS, and less than 15% of the results for those nine contaminants were non-detects with the RLs exceeding the SQS. Appendix C presents samples with non-detected results with RLs that are greater than the SQS and are outside of remedial footprints. It is anticipated that at least 77% of the EW OU will be remediated, further reducing the impact of the uncertainty of laboratory reporting limits.

- **Sampling Design**: Another portion of uncertainty is related to the design of the various past sampling programs represented in the SRI/FS baseline dataset. A few historical investigations have targeted specific areas (e.g., the Phase 1 dredge area) and, therefore, have much denser sampling coverage than other areas of the EW. The experimental designs for collecting SRI samples were developed in consultation with EPA to achieve adequate spatial representation throughout the entire study area, considering existing data determined to be acceptable for use in the SRI and FS.[80] Good spatial coverage exists throughout the EW; however, sample locations in some areas are more evenly distributed than others. For this reason, the areal extent of contamination has some uncertainty, which is common in the feasibility study phase of any project. However, since most of the EW OU is within the remediation area, this uncertainty is relatively small. The delineation will be refined during remedial design.
- **Interpolation Methods:** Thiessen polygon interpolation methods were used to map surface sediment and shallow subsurface sediment data. These methods, like all interpolation methods, have inherent uncertainties, including the density of samples, influence of geomorphology on the distribution of contaminants, and influence of surrounding data. The selected Thiessen polygon technique is well documented and widely used for managing contaminated sediments. Appendix C presents the rationale

[80] To refine the extent of known contaminated areas, additional sampling may be needed during remedial design. Design sampling will be conducted to refine the areal extent of the cleanup area and vertical extent of contaminated sediments.

for this interpolation method and presents a sensitivity analysis with comparison to another interpolation method.

6.2 Selection of RALs

This section describes the selected RALs and how they were established to achieve each RAO. Once remediation is completed, the achievement of the RAO-specific PRGs is determined based on a site-wide average concentration for RAOs 1, 2, and 4; clamming area average concentrations for RAO 2, and on a point basis evaluation for RAO 3.

RALs are presented below in a stepwise manner, with each RAL resulting in additional area requiring remediation. The remediation area was first developed based on the protection of benthic invertebrates (RAO 3) because RALs based on RAO 3 risk drivers (including PCBs and arsenic) generate the majority of the remediation area. These RALs are based on SMS benthic numerical criteria (these are the RBTCs for benthic community) and the TBT RBTC (Figure 6-1). Then, additional remediation areas were added based on RALs for total PCBs and dioxins/furans, because these RALs add the second largest remediation area (Figures 6-3 and 6-4). The area requiring remediation was delineated where any of these compounds exceeded the RAL concentrations described below.

6.2.1 RAO 3 (Protection of Benthic Invertebrates) RAL

The area requiring remediation includes locations with detected concentrations of the benthic community risk drivers above the SQS (RALs are equal to the RAO 3 PRGs). Each Thiessen polygon shown on Figure 6-1 was classified as an SQS exceedance if one or more detected SMS contaminants exceeded this criterion in the 0- to 10-cm interval of sediment or 0- to 2-foot interval of subsurface sediment north of the Spokane Street Bridge (see Section 6.1.2.1). Toxicity test results were included in the final classifications with passing toxicity results trumping the chemistry results, except for polygons that exceeded the SQS for PCBs because PCBs are also a human health COC. The OC-normalized concentrations were used for total PCBs and other non-polar organic compounds when the TOC content was within the appropriate range for OC-normalization (0.5% to 4.0%); otherwise dry weight LAET values were used to establish whether a sample was above or below SMS criteria.[81] The PRGs for SMS chemicals are expected to be achieved site-wide immediately after construction in open-water areas.

For RAO 3, the area requiring remediation was expanded to include locations with TBT concentrations above the RBTC (and, thus, PRG). The density and spatial extent of TBT sample locations were not adequate to develop area-wide Thiessen polygons. Therefore, each surface sediment or shallow subsurface sediment location (north of the Spokane Street Bridge) that was analyzed for TBT was compared to the RBTC of 7.5 mg/kg OC (Figure 6-1). All TBT sample locations exceeding the RBTC are already included in the area requiring remediation based on SMS criteria exceedances, except for one sample from the 0- to 2-foot interval at EW-SC100. For that location, a polygon was constructed to encompass an estimated exceedance area, using best professional judgement considering the chemical data from nearby samples for TBT and other benthic risk driver COCs (area shown on Figure 6-1). The PRG for TBT is expected to be achieved immediately after construction in open-water areas.

As shown on Table 4-5, 29 risk driver COCs exceeded the SQS. RALs were not developed for all of these benthic risk drivers, rather RALs were developed for a subset of these risk drivers (referred to as indicator SMS chemicals). These indicator SMS chemicals consist of 1,4-dichlorobenzene, acenaphthene, arsenic, butyl benzyl phthalate, fluoranthene, fluorene, mercury, phenanthrene, and total PCBs. RALs are not established for each of the other benthic risk driver COCs (e.g., other SMS contaminants) because site-specific analysis shows that remediation to address these nine contaminants also addresses the other SMS contaminants that are above the SQS. This analysis was performed using the project database: surface sediment and shallow subsurface samples (Section 6.1.1) that exceeded the RALs for any of the nine indicator COCs were removed from the dataset, resulting in no additional benthic exceedances remaining. This shows that at least one of the nine indicator COCs are always co-located with the remaining benthic COCs. Thus, based on analysis of the SRI/FS dataset, the subset of SMS chemicals represents the full extent of SQS exceedances in surface and shallow subsurface

[81]The lowest-apparent-effect threshold (LAET) is used as the dry weight equivalent to SQS for compounds with organic carbon-nomalized criteria for samples outside of the appropriate total organic carbon range. The second-lowest-apparent-effect threshold (2LAET) is used as the dry weight equivalent to benthic CSL for compounds with organic carbon-nomalized criteria for samples outside of the appropriate total organic carbon range for carbon-normalizing. LAET and 2LAET values can be found in SCUM II (Ecology 2017).

sediments. Note that the depth of contamination determined by the indicator chemicals also encompasses exceedances from the full set of risk driver COCs. The area requiring remediation above the RALs for RAO 3 constitutes 120 acres, or 76% of the OU (Figure 6-1).

Refinement to the remediation area, as necessary, considering all benthic risk driver COCs will be determined during remedial design. All SMS COCs will be monitored after remediation and monitoring will determine if additional actions are warranted.

6.2.2 RAO 1 (Human Health Seafood Consumption) RALs

For this FS, progress toward achievement of RAO 1 (reduction of human health risks from seafood consumption) is assessed based on estimated reductions in the site-wide SWAC of total PCBs and dioxins/furans. cPAHs were also identified as a risk driver for RAO 1, and are discussed in this section.

The total PCB and dioxin/furan PRGs for RAO 1 are based on natural background concentrations in this FS. Because PRGs based on natural background are not expected to be achieved (Appendix A), RALs were developed to reduce site-wide SWACs which would, in turn, reduce associated risks for RAO 1. Table 6-1 presents the RALs and their predicted outcomes with respect to SWACs and RAOs.

Because the PCB PRG of natural background for RAO 1 cannot be achieved in the EW, three different RALs were developed and screened to evaluate effectiveness, cost, and implementability of the RALs (see Appendix L for more details). For total PCBs, a "hill-topping" evaluation was conducted to select the screening RALs by ranking the measured surface and shallow subsurface sediment PCB concentrations from highest to lowest. The highest values were sequentially replaced with a post-remedy bed sediment replacement value (see Appendix B Part 3) to estimate the site-wide SWAC after each of the values (and associated estimated remediation area) was removed from the dataset. Figure 6-2 presents the hill-topping results for total PCBs, showing the relationship between RAL, area remediated, and resulting SWAC. Note that the analysis is performed on dry weight concentrations; however, PCB RALs are measured as carbon-normalized concentrations, to be consistent with the marine benthic standard and to acknowledge the role of organic carbon in PCB bioavailability.

The hill-topping results shown on Figure 6-2 informed the selection of the three screening RALs for total PCBs: 12 mg/kg OC (equivalent to 192 µg/kg dw), 7.5 mg/kg OC (equivalent to 120 µg/kg dw), and 5.0 mg/kg OC (equivalent to 80 µg/kg dw).[82] As shown in Figure 6-2, each of these screening RALs is below the "knee of the curve," or the point at which further reductions in the RAL does not result in an appreciable reduction in the site-wide SWAC. The hill-topping also demonstrates that all three PCB RALs in Figure 6-2 are similar to the best estimate of incoming sediment concentrations, limiting the possibility that site-wide concentrations would increase due to incoming sediment following remediation. Figure 6-3 shows the remediation areas associated with these three screening RALs for PCBs, along with the RALs for the other COCs.

PCB RALs retained for detailed evaluation are 12 mg/kg OC and 7.5 mg/kg OC. The 12 mg/kg OC RAL is the highest RAL considered because it is the same as the PRG for protection of benthic invertebrates (RAO 3) and achieves the PRG for protection of ecological health (RAO 4). The second PCB RAL of 7.5 mg/kg OC was selected to evaluate the effect of a lower RAL in the FS (Appendix L).

An additional screening RAL for total PCBs of 5.0 mg/kg OC was considered for inclusion in the detailed evaluation of alternatives. However, the RAL was screened out because it does not result in a decrease in SWAC beyond that achieved by the RAL of 7.5 mg/kg OC (Appendix L).

A dioxin/furan RAL of 25 ng TEQ/kg dw was selected for consistency with the LDW ROD (EPA 2014) and to achieve the lowest achievable concentrations in the EW. The area of the EW requiring remediation was expanded beyond the area identified based on RAO 3 to include any dioxin/furan concentrations above the RAL of 25 ng TEQ/kg dw measured in discrete surface and shallow subsurface sediment samples. Based on this criterion, three Thiessen polygons were added to the area requiring remediation to address dioxin/furan RAL

[82] All dry weight equivalents are based on average TOC of 1.6% in EW surface sediments.

exceedances (Figure 6-4). Two polygons were added based on two surface sediment sample concentrations above the RAL, and one polygon within Slip 27 was added because the subtidal composite sample representing Slip 27 is above the dioxin/furan RAL.

cPAHs were also identified as a risk-driver for RAO 1, but an RBTC could not be developed. As discussed in Section 3.3, sediment RBTCs based on the seafood consumption pathway were not calculated for cPAHs because correlation between sediment contaminant concentrations and clam tissue concentrations (the seafood type resulting in unacceptable human health risk) could not be established. However, achieving PRGs for RAO 3 are expected to also reduce sediment cPAH concentrations and the risk associated with the consumption of seafood. Though, consistent with the LDW, data showed little relationship between clams and sediment for cPAHs, and thus the amount of risk reduction from sediment remediation is unknown. The clam concentrations may be more related to the water pathway, and water exposures can be related to incoming water from upstream or downstream of the site.

When adding together the remediation areas for protection of RAO 1 to the remediation area for protection of RAO 3 (which includes the PCBs RAL of 12 mg/kg OC), the remediation area increases to 121 acres (1 additional acre) by incorporating the dioxin/furan RAL of 25 ng TEQ/kg dw (77% of the sediment area). The remediation footprint increases to 132 acres when expanding the area for the PCB RAL of 7.5 mg/kg OC (84% of the sediment area).

6.2.3 RAO 2 (Human Health Direct Contact) RALs

Achievement of RAO 2 is assessed on two spatial scales using two direct contact exposure scenarios: 1) site-wide for tribal netfishing; and 2) area-wide within existing and potential future clamming areas based on tribal clamming. Achieving the clamming PRG for RAO 2 requires that average sediment COC concentrations be reduced at locations and depths where people that are clamming have the potential to be exposed to sediment. Direct contact risks in the exposed intertidal areas (e.g., sediment areas not under pier) are assumed to result from exposure to the upper 25-cm depth interval. Arsenic is the risk driver COCs for direct contact. For arsenic, the same RAL (57 mg/kg dw applied site-wide) that achieves RAO 3 also achieves RAO 2; it provides overall reductions in sediment concentrations that achieve both the netfishing and clamming PRGs. Areas above the RALs for arsenic are shown in Figure 6-5.

When including site-wide remediation for all RALs (including either 12 mg/kg OC or 7.5 mg/kg OC for total PCBs), 3.3 acres, or 82% of the exposed intertidal area, will be remediated to achieve RAO 2.

6.2.4 RAO 4 (Ecological Receptor Seafood Consumption) RAL

For RAO 4, total PCBs is the only risk driver. Achievement of the PRG is assessed on a site-wide basis. Both the total PCB RALs of 7.5 mg/kg OC and 12 mg/kg OC are predicted to achieve RAO 4 immediately after construction, so no additional areas have been added based on this RAO.

6.3 Summary of RALs

The RALs are summarized in Table 6-1 based on the selection process described in Section 6.2. Figure 6-6 shows the entire remediation area based on these RALs. When adding together the remediation areas needed to address all RAOs, the remediation area is 121 acres when using the PCB RAL of 12 mg/kg OC (77% of the sediment area)[83] and 132 acres when using the PCB RAL of 7.5 mg/kg OC (84% of the sediment area).

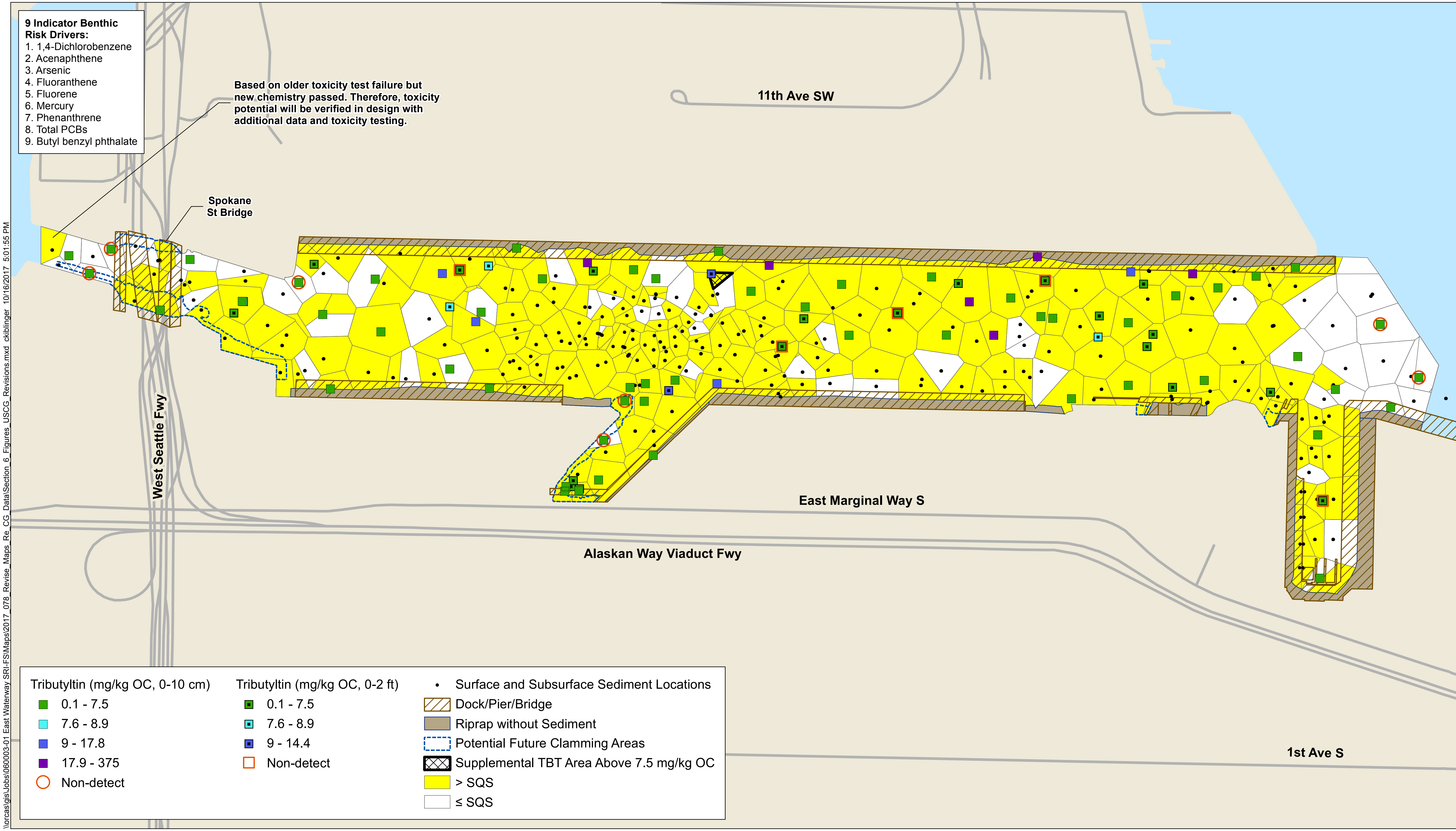
[83] As noted in Figure 6-6, a 0.11-acre modification area is shown as part of the 121-acre remediation area. However, this 0.11-acre area should be removed from the 121-acre remediations area (but retained within the larger 132-acre remediation area), due to a modification in the benzo(a)pyrene cancer slope factor used for cPAHs that occurred during the development of the FS. Because the modification area was not sufficiently large to alter the rounded areas, volumes, and costs for the alternatives, it has been retained as part of the 121-acre remediation area. As discussed elsewhere in the FS (e.g., Appendix G), the remediation areas will be further delineated with additional sampling during remedial design.

Table 6-1
Summary of Selected RALs

Risk Driver	RAL[a]	Data Used for Evaluation[a]	Approximate Post-construction Outcome[b,c]	PRG[d]	Remedial Action Objectives Achieved			
					RAO 1 (Human Health Seafood Consumption)	RAO 2 (Human Health Direct Contact)	RAO 3 (Protection of Benthic Invertebrates)	RAO 4 (Ecological-Fish)
Total PCBs	12 mg/kg OC (site-wide); 7.5 mg/kg OC (site-wide)	Site-wide Thiessen polygons[e]	Achieves 12 mg/kg OC on a point basis	12 mg/kg OC	NA	NA	✓	NA
			Site-wide SWAC of 40 µg/kg dw for both RALs (Appendix L)[f]	2 µg/kg dw	T	NA	NA	NA
				250, 370 µg/kg dw	NA	NA	NA	✓
Arsenic (mg/kg dw)	57 (site-wide)	Site-wide Thiessen polygons[e]	Achieves 57 on a point basis	57	NA	NA	✓	NA
			Site-wide SWAC of 12	7	NA	✓	NA	NA
	57 (clamming areas)	Intertidal polygons[g]	Clamming area SWAC of 12	7	NA	✓	NA	NA
Dioxins/furans (ng TEQ/kg dw)	25 (site-wide)	Site-wide Thiessen polygons[e]	Site-wide SWAC of 5[h]	2	T	NA	NA	NA
Tributyltin (mg/kg OC)	7.5 (site-wide)	Site-wide Thiessen polygons[e]	Achieves 7.5 on a point basis	7.5	NA	NA	✓	NA
SMS Chemicals[i]								
1,4-dichlorobenzene (mg/kg OC)	3.1	Site-wide Thiessen polygons[e]	Achieves 3.1 on a point basis	3.1	NA	NA	✓	NA
Butyl benzyl phthalate (mg/kg OC)	4.9		Achieves 4.9 on a point basis	4.9				
Acenaphthene (mg/kg OC)	16		Achieves 16 on a point basis	16				
Fluoranthene (mg/kg OC)	160		Achieves 160 on a point basis	160				
Fluorene (mg/kg OC)	23		Achieves 23 on a point basis	23				
Mercury (mg/kg dw)	0.41		Achieves 0.41 on a point basis	0.41				
Phenanthrene (mg/kg OC)	100		Achieves 100 on a point basis	100				
Total PCBs (mg/kg OC)	12		Achieves 12 on a point basis	12				
Arsenic (mg/kg dw)	57		Achieves 57 on a point basis	57				

Notes:
a. Point concentrations used to develop site-wide polygons to delineate the area requiring remediation. Intertidal composite concentrations used to develop exposed intertidal polygons to delineate the area requiring remediation.
b. Effective site-wide SWAC is the post remediation SWAC combining both the post remediation SWAC from the areas requiring remediation for all the RALs listed above with the SWACs from the areas below RALs.
c. Replacement values for remediated areas and internal unremediated areas developed and presented in Section 5 were applied for calculation of effective site-wide and intertidal SWACs.
d. PRGs were developed and presented in Section 4.
e. Based on surface (0 to 10 cm) sediment and shallow (0 to 2 feet) subsurface sediment.
f. When considering all COCs that make up the full remediation area, as presented in Appendix L, the effective site-wide SWAC for the RALs of 12 mg/kg OC and 7.5 mg/kg OC were 40 µg/kg when considering effective bioavailability. Effective bioavailability estimates assume a 70% reduction in concentration in remediated underpier areas due to placement of in situ treatment material (see Section 7.2.7.1 for more details). SWACs for PCBs may be higher than indicated due to mixing of sediment left behind due to structural offsets (e.g., underpier areas, keyways, and associated dredging offsets) and dredge residuals (Appendix A). The screening RAL of 5.0 mg/kg OC also achieved similar SWACs (Appendix L).
g. Based on sediment collected from 0 to 10 cm (surface sediment grabs) and 0 to 25 cm (intertidal composites) in intertidal areas.
h. Dioxin/furan surface sediment subtidal composites were used to represent the concentration of unremediated areas for calculation of effective site-wide SWAC.
i. 29 risk driver COCs exceeded the SQS. RALs were selected for nine of these contaminants to represent the entire area above the SQS.
✓ – Achieves PRG immediately following construction or long-term model-predicted concentration.
T – Achieves RAO over time by reducing risks to human health. Institutional controls will be required to further reduce RAO 1 risks for PCBs and dioxins/furans. Compliance with the RAO in the long term will be demonstrated in one of several ways following SMS and CERCLA requirements (see Section 4.3.1).

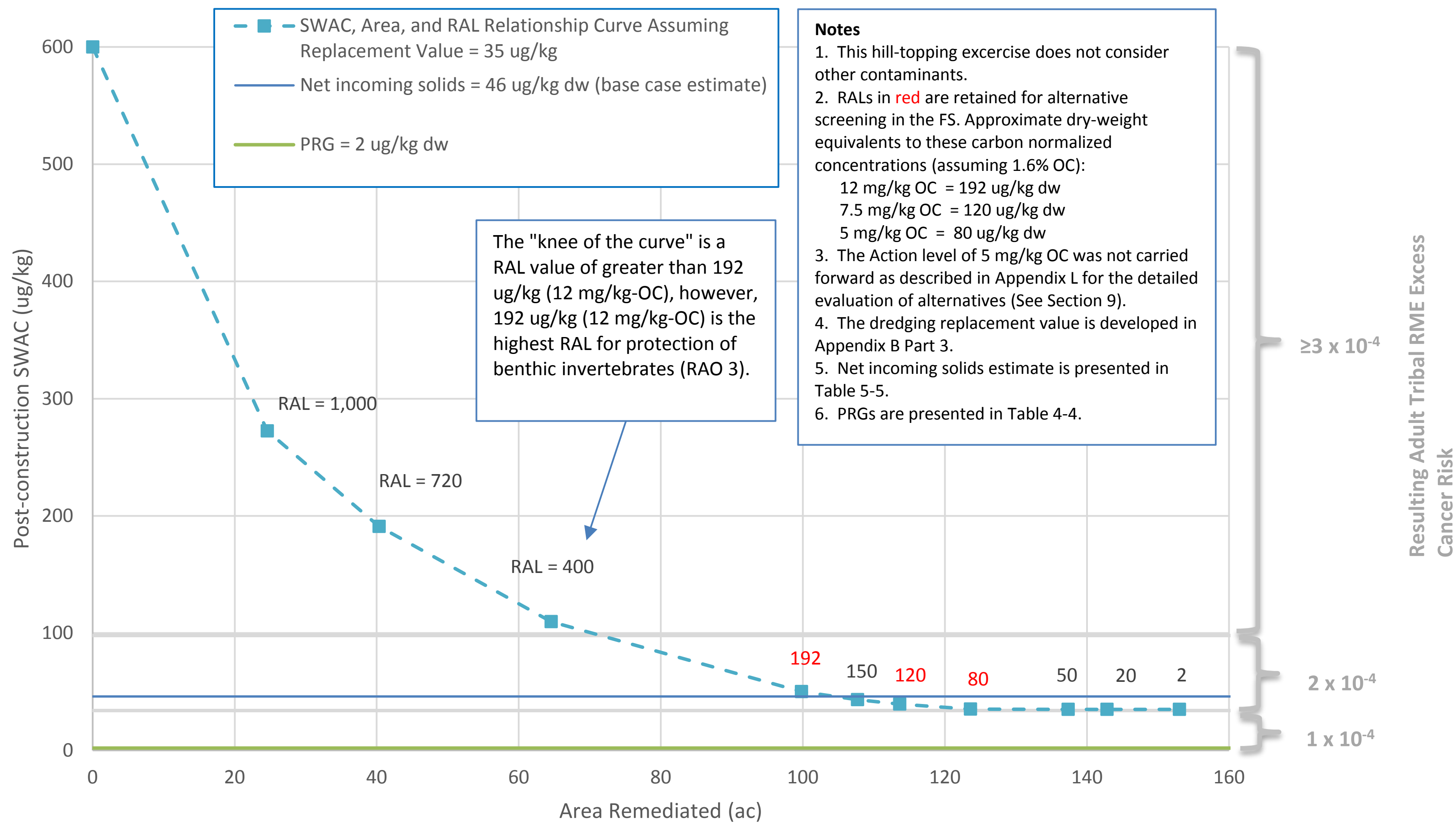
µg – micrograms
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
COC – contaminant of concern
dw – dry weight
kg – kilograms
mg – milligrams
NA – not applicable
NB – natural background
ng – nanograms
OC – organic carbon
PCB – polychlorinated biphenyl
PRG – preliminary remediation goal
RAL – remedial action level
RAO – remedial action objective
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent



NOTES:
1. Thiessen polygons shown include surface sediment polygons (presented in Figure 2-20a-c), further subdivided using shallow subsurface sediment results (0-2 ft) in the area north of the Spokane Street Bridge.
2. Shallow subsurface sediment results were only used to increase (but not decrease) the area exceeding SQS established based on surface sediment data.
3. Benthic toxicity bioassay data resulted in five polygons with chemical exceedances (for chemcals other than PCBs) being removed from the exceedance footprint.
4. Tributyltin RAL = 7.5 mg/kg-OC.

0 250 500 750 1,000
Scale in Feet

Figure 6-1
Benthic Risk Drivers: Exceedances of SQS for Surface Sediment and Shallow Subsurface Sediment
Feasibility Study
East Waterway Study Area



ANCHOR QEA

Figure 6-2
PCBs RALs, Remediation Area, and Resulting Post-construction SWACs
Feasibility Study
East Waterway Study Area

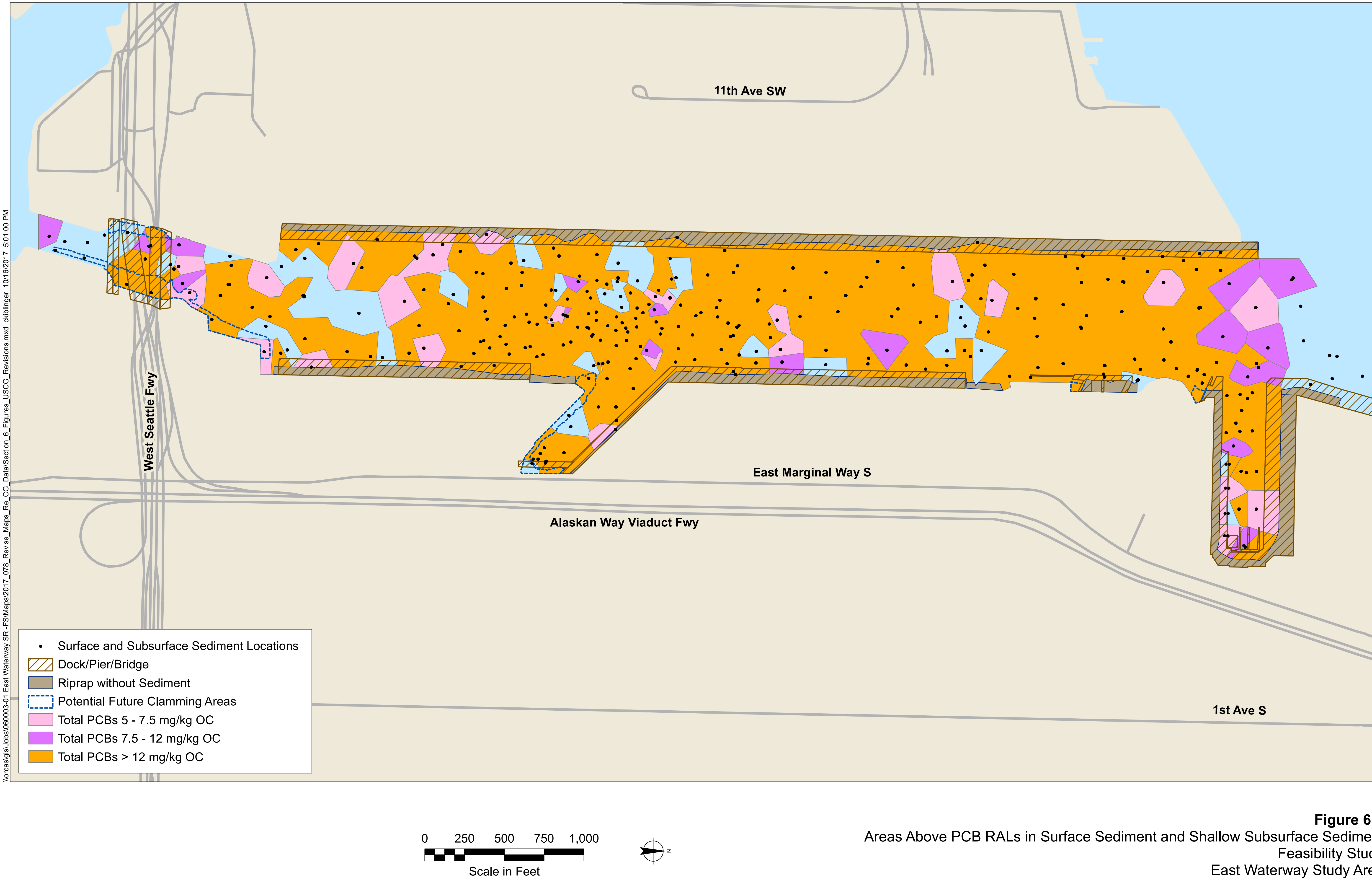
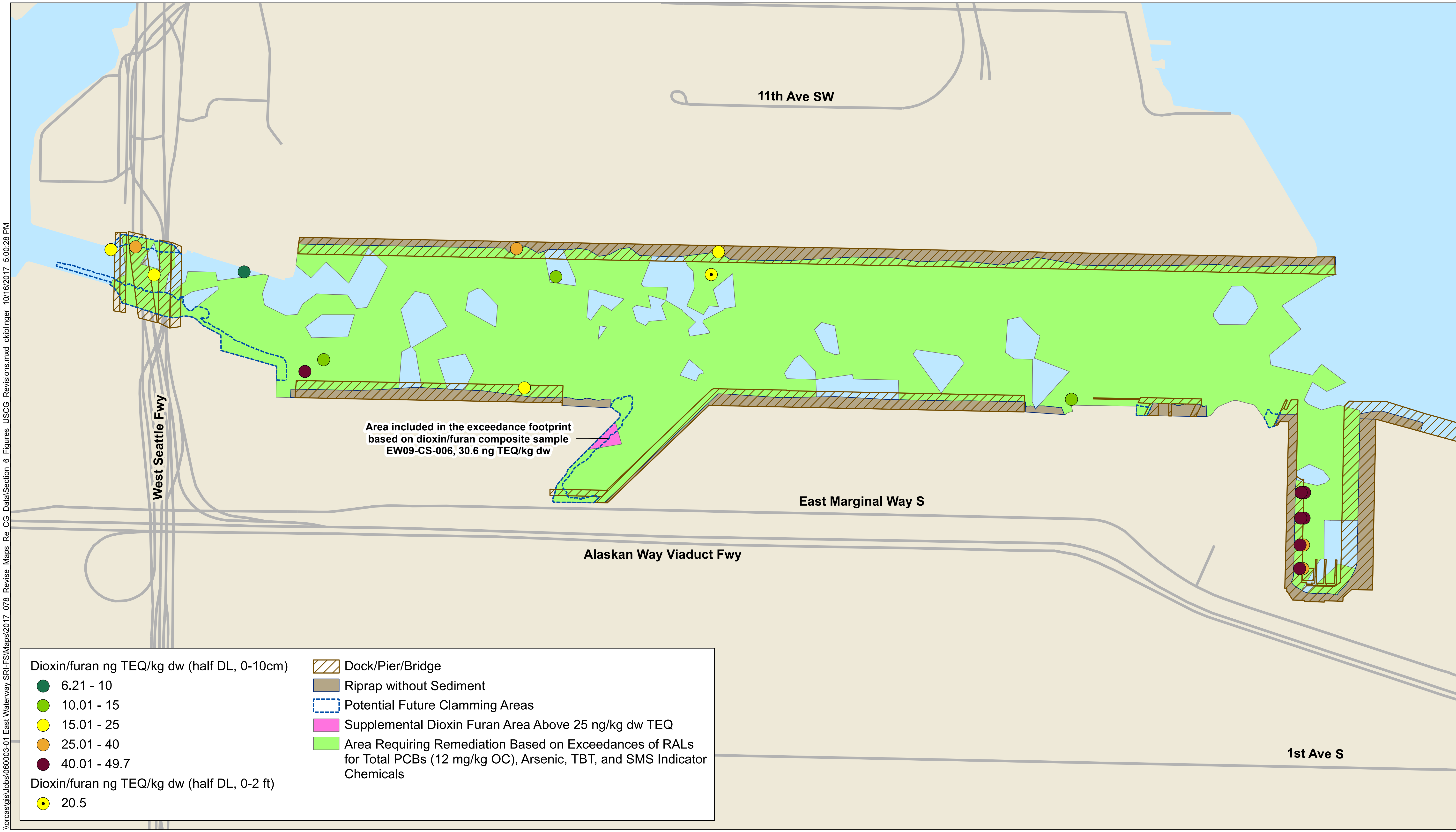
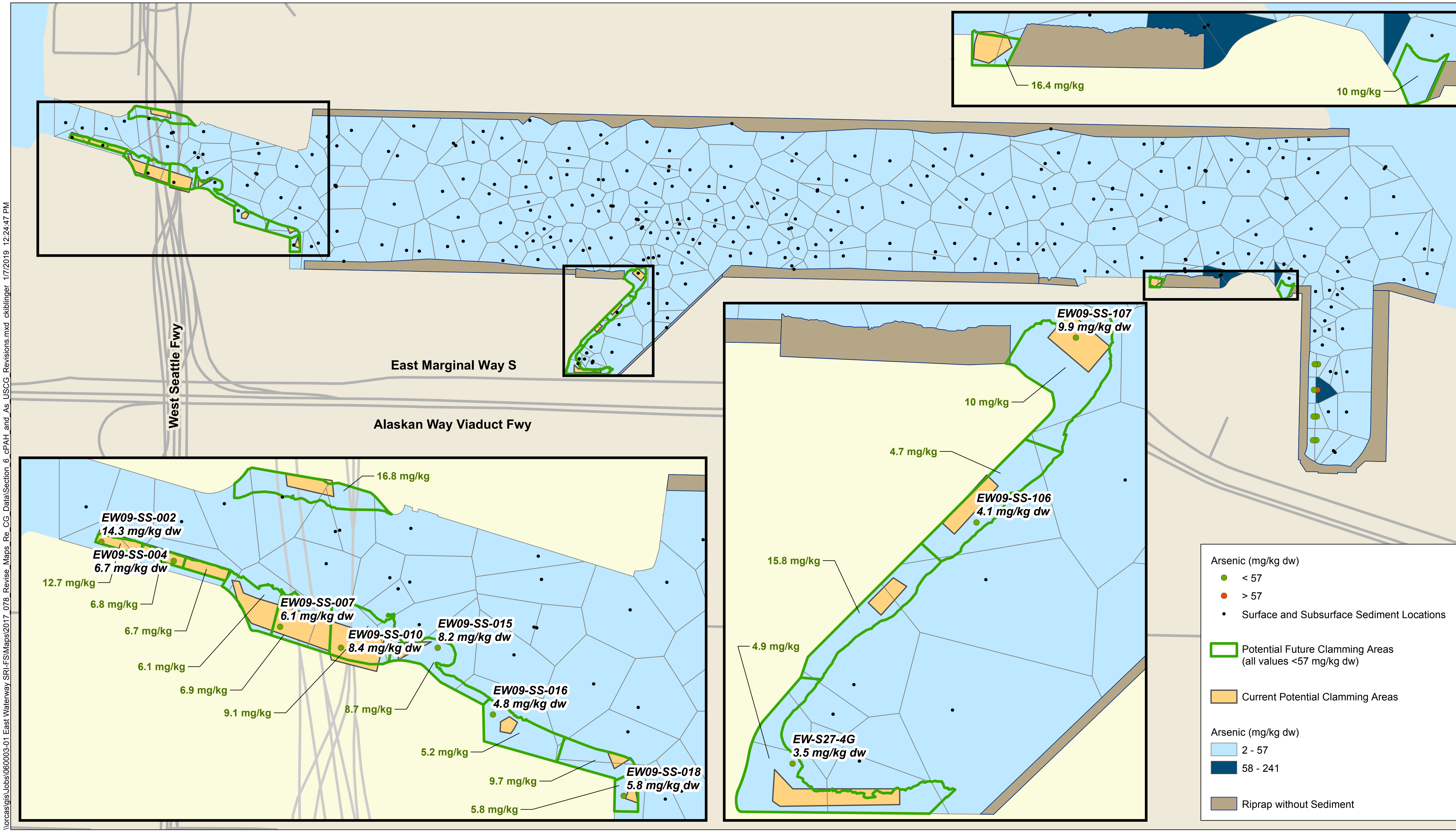


Figure 6-3
Areas Above PCB RALs in Surface Sediment and Shallow Subsurface Sediment
Feasibility Study
East Waterway Study Area



NOTE:
Dioxin/furan RAL = 25 ng TEQ/kg dw.

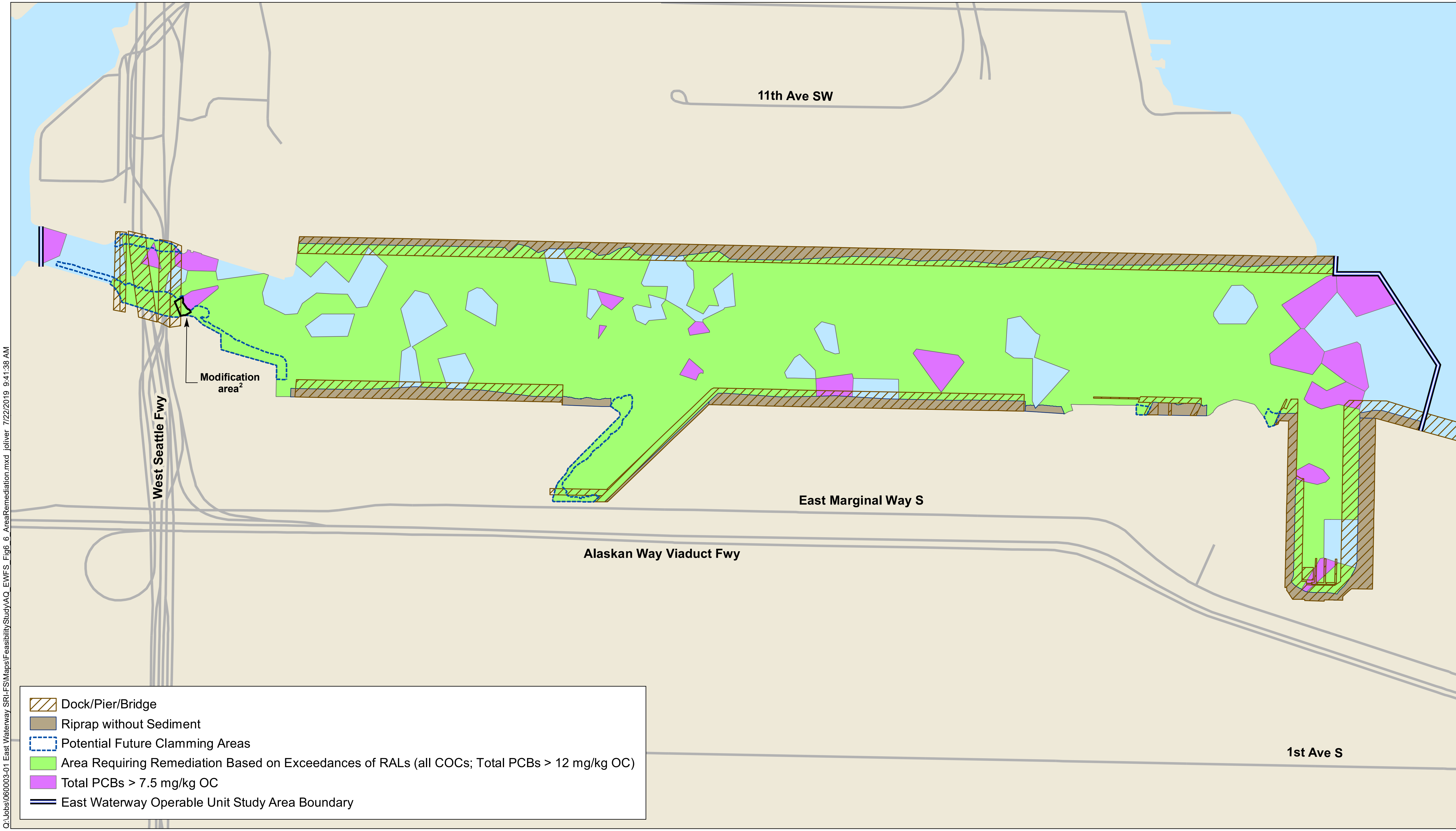
Figure 6-4
Supplemental Areas Above Dioxin/Furan RAL in Surface Sediment and Shallow Subsurface Sediment
Feasibility Study
East Waterway Study Area



NOTE:
Clamming Area and site-wide Arsenic RAL= 57 mg/kg dw.

0 250 500 750 1,000
Scale in Feet

Figure 6-5
Areas Above Site-wide and Intertidal RALs for Arsenic in Surface Sediment and Shallow Subsurface Sediment
Feasibility Study
East Waterway Study Area



NOTES:
1. RAL: Remedial Action Level
2. This 0.11 acre area should technically be shown as part of the dark pink remediation area (Total PCBs > 7.5 mg/kg OC) due to a modification of the benzo(a)pyrene cancer slope factor used for cPAHs that occurred late in development of the FS. For the sake of efficiency, no adjustments were made to the FS from this point forward to reflect this condition because the small areal adjustment has no effect on rounded areas, volumes, and costs. Actual remediation areas will be further delineated with additional sampling during remedial design.

0 250 500 750 1,000
Scale in Feet

Figure 6-6
Area Requiring Remediation
Feasibility Study
East Waterway Study Area

7 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

This section identifies and screens remedial technologies consistent with EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988). This section incorporates the findings of the technology screening conducted for the EW OU in the Screening Memo (Anchor QEA 2012a), which identified and screened a comprehensive set of general response actions (GRAs), technology types, and process options that are potentially applicable to cleanup of contaminated sediments in the EW OU.

This section and the Screening Memo (Anchor QEA 2012a) incorporate work previously completed as part of the LDW FS for screening technologies (AECOM 2012), which has been reviewed by stakeholders and approved by EPA, and is relevant to the EW based on proximity of the sites to each other, similar site conditions, and similar COCs. Screening and retention of many technologies were based on these documents, and those decisions have generally been included in this FS.

Updates to account for any recent technology developments or relevant experience at other cleanup sites since finalization of the Screening Memo (Anchor QEA 2012a) are included in this section. The Superfund Innovative Technology Evaluation Program, the EPA Hazardous Waste Clean-up Information website, and the Federal Remediation Technologies Roundtable were reviewed for recent and relevant information about innovative treatment technologies, including their cost and performance, results of technology development and demonstration, and technology optimization and evaluation. The site-wide identification and evaluation of remedial technologies have generally not been modified from the Screening Memo, and the results of that evaluation are summarized in Sections 7.2 through 7.5. Points of departure from the Screening Memo are noted in the text. The location-specific (i.e., Construction Management Area-specific) evaluation of remedial technologies have been modified from the Screening Memo based on additional information and further analysis of the site; the results of that analysis are presented in Sections 7.6 through 7.7.

Consistent with EPA guidance (EPA 1988), the technologies are presented in a tiered approach intended to provide layers of specificity that will aid in screening technologies for each GRA, Technology Type, and Process Option:

- **General Response Actions**. GRAs may be used individually or in combination to satisfy EW OU site-specific RAOs. For the EW OU, GRAs include no action, institutional controls, monitored natural recovery, enhanced natural recovery, containment, removal, treatment, and disposal.
- **Technology Type**. The next layer of tiered technologies include the remedial and disposal technologies, which categorize technologies within a GRA to achieve RAOs. For example, within the removal GRA, dredging and dry excavation can be used to accomplish the action.
- **Process Options**. Process options are specific processes within each technology that could be employed to accomplish the site RAOs. These process options are selected to address site-specific conditions and constraints. For example, within the dredging technology type, mechanical dredging or hydraulic dredging can be used.

The Screening Memo (Anchor QEA 2012a) evaluation was conducted using the effectiveness, implementability, and cost criteria consistent with EPA guidance (EPA 1988). Effectiveness refers to whether or not a technology can contain, reduce, or eliminate COCs. Implementability refers to whether a technology can be operated under the physical and chemical conditions of the EW, is commercially available, and has been used on sites similar in scale and scope of the EW.

Key considerations in the screening of technologies in the EW include site-specific constraints from structures, aquatic uses, habitat, and water depth. As first introduced in the Screening Memo (Anchor QEA 2012a), the EW OU has been divided into specific CMAs that represent areas with similar structural conditions, or similar aquatic use, habitat, or water depth conditions. The boundaries of some of the CMAs and description of site characteristics have been updated in this section to reflect additional information acquired since finalization of the Screening Memo.

This section identifies and describes representative, effective, and implementable potential remedial and disposal technologies that are retained for incorporation into remedial alternatives described in Section 8. The discussion of retained technologies considers information on past and current sediment remediation projects in the Puget Sound region, elsewhere in EPA Region 10, and nationally where appropriate. Reducing the number of process options does not preclude reexamination of these options during the remedial design phase of the cleanup project. Rather, it is a means to streamline the development and evaluation of the remedial alternatives without sacrificing engineering flexibility.

Specifically, this section consists of the following components:

- A description of the GRAs, technology types, and process options (Section 7.1)
- A description of each remedial technology and screening decisions (Section 7.2)
- A description of each disposal technology and screening decisions (Section 7.3)
- A description of short- and long-term monitoring that may be required before, during, and after construction of the selected remedial alternatives (Section 7.4)
- A description of ancillary technologies that may be employed in combination with other process options (Section 7.5)
- A summary of the general site conditions affecting remedial technology selection (Section 7.6)
- A description of critical site constraints in the EW affecting the implementability of certain technologies (Section 7.7)
- Evaluation of remedial technologies for CMAs (Section 7.8)

The complete screening process is summarized in tables as follows:

- Table 7-1 (see Section 7.1) lists all of the candidate remedial technologies and process options that were evaluated in the FS process, along with the screening for applicability
- Table 7-2 (see Section 7.6) summarizes general site conditions affecting remedial technology selection
- Table 7-3 (see Section 7.7) provides descriptions of EW OU CMAs based on site restrictions that affect the selection of applicable remedial technologies
- Table 7-4 (see Section 7.8) integrates the critical site constraints information with the retained remedial technologies, to show where each retained technology is applicable within a particular area and which technologies are carried forward in the alternatives analyzed in Section 8.

7.1 Review and Selection of Representative Technologies

In accordance with CERCLA guidance, cleanup technologies are organized under GRAs that represent different conceptual approaches to remediation. These GRAs include the following:

- No Action
- Institutional Controls
- Natural Recovery (including MNR and ENR)
- In situ Containment
- Removal
- In situ Treatment
- Ex situ Treatment
- Disposal

Table 7-1 describes the GRAs, technology types, and process options potentially appropriate to the EW OU sediments, and identifies whether they were screened out or retained for consideration in the FS in the Screening Memo (Anchor QEA 2012a). Each of the retained technologies is discussed in subsequent sections. The screened technologies form the basis for this FS; however, additional information could lead to the reconsideration of eliminated technologies during remedial design. Remedial technologies are described in Section 7.2, and disposal technologies are described in Section 7.3.

7.2 Remedial Technologies

The identification and screening evaluation of potentially applicable remedial and disposal technologies are provided in the sections below.

7.2.1 No Action

No Action is a retained technology as required per CERCLA. No Action will be used as a baseline comparison against other technologies. No Action requires no human intervention but can include long-term monitoring to ensure that there are no long-term unacceptable risks to the environment or human health (EPA 1988). No Action can only be selected where the site poses no unacceptable risks to human health or the environment.

Table 7-1
East Waterway Technology Screening

<table>
<tr><th>General Response Action</th><th>Technology Type</th><th>Process Option</th><th>Implementability</th><th>Effectiveness</th><th>Cost</th><th>Screening Decision</th></tr>
<tr><td>No Action</td><td>None</td><td>Required by National Contingency Plan</td><td>High</td><td>Low</td><td>Low</td><td>Retained</td></tr>
<tr><td rowspan="2">Institutional Controls</td><td>Proprietary Controls</td><td>Access and property use restrictions; maintenance agreements</td><td>Moderate</td><td>Low to Moderate</td><td>Low</td><td>Retained</td></tr>
<tr><td>Informational Devices</td><td>• Monitoring and notification of waterway users
• Seafood consumption advisories, public outreach, and education
• Enforcement tools
• Environmental Covenants Registry</td><td>High</td><td>Low</td><td>Low</td><td>Retained</td></tr>
<tr><td rowspan="2">Natural Recovery</td><td>Monitored Natural Recovery</td><td>Sedimentation</td><td>High</td><td>Moderate</td><td>Low</td><td>Retained</td></tr>
<tr><td>Enhanced Natural Recovery</td><td>Placement of thin layer of clean cover</td><td>High</td><td>Moderate</td><td>Low to Moderate</td><td>Retained</td></tr>
<tr><td rowspan="3">In situ Containment</td><td rowspan="3">Cap</td><td>Conventional Cap</td><td>Moderate</td><td>High</td><td>Moderate</td><td>Retained</td></tr>
<tr><td>Low-permeability Cap</td><td>Low</td><td>High</td><td>Moderate to High</td><td>Not Retained</td></tr>
<tr><td>Reactive Cap</td><td>Low</td><td>High</td><td>Moderate to High</td><td>Retained</td></tr>
<tr><td rowspan="3">Removal</td><td>Dry Excavation</td><td>Excavator</td><td>Low</td><td>Moderate to High</td><td>High</td><td>Retained (in limited areas)</td></tr>
<tr><td rowspan="2">Dredging</td><td>Mechanical Dredging</td><td>Moderate to High</td><td>Moderate to High</td><td>High</td><td>Retained</td></tr>
<tr><td>Hydraulic Dredging</td><td>Low in Open-water Areas; Low to Moderate in Underpier Areas</td><td>Moderate to High</td><td>High</td><td>Retained for Underpier Areas to the extent practicable; not retained elsewhere</td></tr>
<tr><td rowspan="13">In situ Treatment</td><td rowspan="5">Physical-Immobilization</td><td>Amendments (e.g., activated carbon, organoclays)</td><td>High</td><td>Moderate to High</td><td>Moderate to High</td><td>Retained</td></tr>
<tr><td>Stabilization</td><td rowspan="12" colspan="4">Not retained</td></tr>
<tr><td>Electro-chemical Oxidation</td></tr>
<tr><td>Vitrification</td></tr>
<tr><td>Ground Freezing</td></tr>
<tr><td rowspan="4">Biological</td><td>Slurry Biodegradation</td></tr>
<tr><td>Aerobic Biodegradation</td></tr>
<tr><td>Anaerobic Biodegradation</td></tr>
<tr><td>Imbiber Beads</td></tr>
<tr><td rowspan="2">Chemical</td><td>Slurry Oxidation</td></tr>
<tr><td>Oxidation</td></tr>
<tr><td rowspan="2">Physical-Extractive Processes</td><td>Oxidation</td></tr>
<tr><td>Sediment Flushing</td></tr>
</table>

Table 7-1
East Waterway Technology Screening

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Cost	Screening Decision
Ex situ Treatment	Physical/Chemical	Acid Extraction	Not retained			
		Solvent Extraction				
		Slurry Oxidation				
		Reduction/Oxidation				
		Dehalogenation				
		Sediment Washing				
		Radiolytic Detoxification				
	Biological	Enhanced Bioremediation				
		Slurry-phase Biological Treatment				
		Fungal Biodegradation				
		Landfarming/Composting				
		Biopiles				
	Physical	Separation	Not retained (may be considered for remedial design)[a]			
		Solar Detoxification	Not retained			
		Solidification				
	Thermal	Incineration				
		High-temperature Thermal Desorption				
		Low-temperature Thermal Desorption				
		Pryolysis				
		Vitrification				
		High-pressure Oxidation				
Disposal	On-site disposal	Confined Aquatic Disposal	Low	Moderate to High	High	Not retained
		Slip 27 NCDF	Low	Moderate to High	High	Not retained
		Slip 36 NCDF	Low	Moderate to High	High	Not retained
	Off-site Disposal	T-5 NCDF	Low	Moderate to High	High	Not retained
		Landfill	High	High	High	Retained
		Open-water Disposal	Low	Low	Low	Not retained
		Beneficial Use	Low	Low	Low	Not retained

Notes:
Shaded cells indicate technologies retained in the Screening Memo (Anchor QEA 2012a).
a. Physical separation was retained in the Screening Memo (Anchor QEA 2012a), but is not retained for developing and comparing remedial alternatives in the FS. Physical separation may be considered in conjunction with other disposal options during remedial design.
NCDF – Nearshore Confined Disposal Facility

7.2.2 Institutional Controls

Institutional controls are non-engineered measures that may be selected as remedial or response actions in combination with engineered remedies, such as administrative and legal controls that minimize the potential for human exposure to contamination by limiting land or resource use (EPA 2000b). The NCP sets forth environmentally beneficial preferences for permanent solutions, complete elimination rather than control of risks, and treatment of principal threats to the extent practicable. Where permanent and/or complete elimination are not practicable, the NCP creates the expectation that EPA will use institutional controls to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. It states that institutional controls may not be used as a sole remedy unless other measures are determined not to be practicable, based on balancing trade-offs among alternatives (40 CFR 300.430 [a][1][iii]).

EPA recommends that where they may provide greater protection, multiple institutional controls should be used in combination, referred to as "layering." Institutional controls may be an important part of the overall cleanup at a site, whenever contamination is anticipated to remain following remediation at concentrations that exceed cleanup levels. Institutional controls may be applied during remedy implementation to minimize the potential for human exposure (as temporary land use or exposure limitations). These controls may also extend beyond the end of construction (or be created at that time) or even after RAOs are achieved to ensure the long-term protectiveness of remedial actions that leave contaminants on site above cleanup levels (as long-term or permanent limitations, e.g., protecting a contaminant barrier like a sediment cap from being accidentally breached).

Institutional controls potentially applicable to cleanup of the EW OU are identified and discussed below. This section describes specific individual controls in sufficient detail to allow for a comparison of remedial alternatives that include various types and degrees of reliance on institutional controls. An integrated Institutional Controls Implementation Plan for the EW that meets specific location, tribal, and community needs is anticipated after the ROD is issued. These considerations are discussed further in the FS as part of the development and evaluation of remedial alternatives (Sections 8 and 9).

EPA guidance broadly lists four types of institutional controls: governmental controls, proprietary controls, enforcement tools, and informational devices. However, governmental controls such as the permitting of some discharges to the EW or dredging and filling of the EW, as well as some enforcement controls, such as consent decrees or administrative orders under which settling parties implement remedies including institutional controls, are not discussed at depth in this FS because they do not affect the choices among alternative remedies; however, they are included in Table 7-1 for general information. These governmental controls are, for remedy selection purposes, uniform across all alternatives and options, and consent decrees will be used if responsible parties implement any or all of any remedial action that EPA selects in the ROD as required by Section 122(d) of CERCLA. Therefore, the most important institutional controls, or aspects of them, that will be considered for the development of remedial alternatives are emphasized below. Enforcement tools, even though they are used, for example, to establish enforceable proprietary controls pursuant to consent decrees or orders, are discussed under the category of informational devices. It should be clear that many categories overlap and that the agency guidance that created them was intended to be helpful in analyses rather than necessarily invent divisible categories (e.g., proprietary controls have government enforcement mechanisms to ensure their continuation, and some informational devices can be related to or enhanced by governmental enforcement programs):

- Proprietary controls
- Informational devices
  - Monitoring and notification of waterway users
  - Seafood consumption advisories, public outreach, and education
  - Enforcement tools
  - Environmental Covenants Registry

These types of institutional controls are outlined below.

7.2.2.1 Proprietary Controls

Proprietary controls are recorded rights or restrictions placed in property deeds or other documents transferring property interests that restrict or affect the use of property. A covenant is a grant or transfer of contractual rights. An easement is a grant of property rights by an owner, often for a specific purpose (e.g., access, utility, and environmental, among other types of easements). Covenants and easements are essentially legally binding arrangements that allow or restrict usage of property for one or more specific objectives (e.g., habitat protection or protection of human health). They commonly survive the transfer of properties through real estate transactions and are binding on successors in interest who have not participated in their negotiation. This distinguishes covenants and easements from ordinary contracts or transactions between or among parties. At cleanup sites, covenants and easements commonly control or prevent current and future owners from conducting or allowing activity that could result in the release or exposure of buried contamination for as long as necessary. Potential activities controlled or prohibited may include in-water activities (e.g., anchoring, spudding, or vessel or tug maneuvering) and construction activities (e.g., pile driving and pulling, dredging, or filling) where buried contamination may become exposed as a result of the activity, as long as it is an activity that the owner may legally control. Selecting a less expensive remedy in the form of a proprietary control that limits future property uses in ways that a more expensive remedy would not involves a complex balancing of interests by EPA. For example, a proprietary control can lower remedial costs for a former owner at the expense of the redevelopment options of a current owner, who acquired the property after it was contaminated. For this reason, among others, EPA policy and guidance stress assessing reasonably anticipated future land use as an important part of remedy selection generally, and specifically stress limiting use of institutional controls.

In Washington State, Ecology has the right to enforce covenants created under MTCA. More recently, Washington passed its Uniform Environmental Covenants Act (UECA), which allows EPA, as well as the state (in addition to the parties to an UECA covenant), to enforce environmental covenants. For this reason, UECA covenants are anticipated to be the primary proprietary control used in EW environmental cleanup actions, if selected as part of a cleanup remedy.

Parties with sufficient ownership interests in shorelines and aquatic land could grant UECA covenants that would help ensure that remedial measures (such as sediment caps) are not disturbed. However, UECA covenants may not be implementable or practicable for portions of the EW where access and use are difficult to control. Another uniquely important interest to consider is the extent to which public entity-granted covenants may interfere with tribal treaty-protected seafood harvesting, in particular.

7.2.2.2 Informational Devices

Monitoring and Notification of Waterway Users

Notification, monitoring, and reporting programs are an example of an informational device potentially applicable. Under such a program, the protection of areas where contamination remains above levels needed to meet RAOs, including areas where capping has been utilized, could be enhanced.

Such areas could be periodically monitored (by vessels and/or surveillance technology), with vessels performing the dual role of educating potential violators of the existence of activity restrictions and promptly reporting violations of use restrictions to EPA, or USCG if an area within the EW OU were formally designated as a Restricted Navigation Area (RNA) by formal USCG rulemaking as described in Section 7.2.2.3. Notification to waterway users could further be provided through enhanced signage and other forms of public notice, education, and outreach. A mechanism for the review of any USACE navigation dredging plans and other Joint Aquatic Resource Permit Application (JARPA) construction permitting activity could be established. The review would identify any projects that may compromise containment remedies or potentially disturb contamination remaining after remediation, which would include a requirement to promptly notify EPA during the permitting phase of any project that could affect cleanup remedies. This mechanism would serve as a backup to an existing Memorandum of Agreement between EPA and USACE for coordinating such permitting, especially if that agreement were to lapse or be discontinued for any reason by either agency in the future.

Additional measures could include: 1) establishing an EW cleanup protection hotline that private citizens could call or email to report potential violations, with a requirement that reports be investigated and conveyed to EPA (and the USCG for any RNAs) under specified protocols; and 2) developing and implementing periodic seafood consumption surveys to identify, by population group and geographical location, which seafood species are consumed, where they are consumed, and in what quantities they are consumed. This information would be used to update the Institutional Control Implementation and Assurance Plan (ICIAP) as appropriate and improve seafood consumption advisories and associated public outreach and education. Additional monitoring of the effectiveness of these tools can be used to adapt this approach, as discussed in the next section. The effectiveness of all these measures could be re-evaluated periodically to assess which ones should be continued or be modified.

Seafood Consumption Advisories, Public Outreach, and Education

The Washington State Department of Health (WDOH) publishes seafood consumption advisories in Washington. WDOH currently recommends no consumption of resident seafood from the EW. Salmon are not resident in the EW; they are anadromous species that spend most of their lives outside of estuaries like the EW and LDW. WDOH recommendations for EW salmon are the same as for Puget Sound as a whole (e.g., no more than one meal per week of Chinook salmon). WDOH maintains a website that includes its advisories and provides publications and other educational forums that cover healthy eating and seafood consumption. In addition, WDOH seafood consumption advisories are posted on signs at public access locations in the EW. Following these advisories is wholly voluntary, which limits the effectiveness of advisories.

The Washington State Department of Fish and Wildlife (WDFW) develops and enforces seasonal restrictions on recreational fishing and seasonal and daily catch limits per individual for various seafood species. All recreational fishers over 15 years of age must have a fishing license and comply with specific size, species, and seasonal restrictions on fishing for fish and shellfish throughout the Puget Sound region. While WDFW summarizes the WDOH seafood consumption advisories, which may enhance their reach and effectiveness, they do not prohibit fishing or shellfishing within the EW. Under WDFW regulation, it is lawful to seasonally collect certain fish and shellfish from the EW. Concerns associated with the use of these institutional controls include the burden placed on tribes exercising their treaty rights and other fishers who use the EW. Relying on seafood consumption advisories to further reduce human health risks may require fishers to change behavior or make cultural adjustments. This burden is difficult to assess precisely given the broad range of needs different fishers may have.

The application of community-based social marketing concepts (EPA 2009a, 2009b) could be employed in the EW to reduce the limitations of seafood consumption advisories and improve the effectiveness of existing seafood consumption advisories for protecting human health. The overarching goal of these efforts would be to develop and implement a public outreach and education program that focuses on incentives and activities that research indicates have the greatest likelihood of adoption and would make the greatest substantive difference in environmental health. Ideally, the program would be coordinated with other health-based initiatives such as the City of Seattle's urban agriculture initiative.

A significant difference between other community-based social marketing sites and the EW (and the LDW) is the presence of tribal fishing rights in the EW secured by treaties of the United States. Nothing in this section or anywhere in this FS is intended to suggest that exercise of such rights, or the underlying cultural traditions, would be precluded by seafood consumption advisories and related programs to reduce contaminated seafood consumption as part of EW remedial action. For this reason, the seafood consumption advisories and public outreach education programs should be developed in consultation with affected tribes to develop accommodations for such tribes to the greatest extent practicable.

7.2.2.3 Enforcement Tools

RNAs are a form of notification program that are created by the promulgation of formal rules by the USCG. RNAs represent an enforceable means of protecting containment remedies and other areas where contamination remains from anchoring and other physical interference, particularly where UECA covenants or other proprietary controls may not be achievable. To the extent that RNAs may potentially interfere with seafood harvest activities, particularly tribal harvests, engineered or alternate means of accommodating fish harvest should be devised (e.g., alternative means of allowing anchoring or tying off a net within a RNA-created no-anchor zone). Although this option has the significant potential to regulate potential impacts associated with anchorage, barge spudding, and tugboat propeller wash, it could restrict maritime commerce or preclude commercial activities generally necessary for construction, maintenance, and operation of commercial piers, depending on where the RNA was located. Like proprietary controls in general, even for sediment areas in private ownership, RNAs require a careful and often highly complex balancing of competing interests and may only be useful in certain locations or circumstances.

7.2.2.4 Environmental Covenants Registry

Placement and maintenance of EW areas with containment remedies, or anywhere where contamination remains above levels needed to meet RAOs, on Ecology's Environmental Covenants Registry in its Integrated Site Information System would provide information regarding applicable restrictions (RNAs and proprietary controls) to anyone who uses or consults the state registry.

7.2.2.5 Institutional Controls Summary

In summary, it must be emphasized that all of the institutional controls, where necessary, are an important component of a remedy. However, enforcement of institutional controls requires monitoring. Privately owned sediments, like publically owned sediments, in an urban commercial waterway are more difficult to guard or restrict uses of than upland properties. Further, it is anticipated that some people, will choose to fish and consume what they catch regardless of fishing regulations, seafood consumption advisories, and robust public outreach and education programs.

7.2.3 Monitored Natural Recovery

Natural recovery is the process by which contaminant concentrations in sediment are reduced through a combination of physical, biological, and chemical processes so that surface sediment concentrations are reduced to acceptable levels within a specified timeframe. Natural recovery includes physical processes (e.g., sedimentation, advection, diffusion, dilution, dispersion, bioturbation, and volatilization), biological processes (e.g., biodegradation, biotransformation, phytoremediation, and biological stabilization), and chemical processes (e.g., oxidation/reduction, sorption, or other processes resulting in stabilization or reduced bioavailability) (EPA 2005). Physical processes act to either bury surface sediment with newly deposited sediments or mix surficial sediment with deeper subsurface sediments through bioturbation, propwash, or other mixing influences. Biological processes can be effective at degrading certain organic compounds, reducing mass or toxicity. Chemical processes, such as absorption of organic chemicals to carbon sources, also may assist with natural recovery.

MNR relies on the natural recovery processes described above and also includes monitoring to ensure that natural recovery is occurring as predicted. MNR differs from long-term monitoring because MNR includes monitoring in specific locations to meet specific target concentrations, and long-term monitoring is used to assess waterway conditions without specific target concentrations. MNR includes adaptive management to determine whether additional remedial actions are necessary. MNR has been approved for remedial actions on many contaminated sediment sites and is considered administratively implementable.

MNR has been shown to be effective at reducing sediment concentrations in CERCLA sites within the Puget Sound, such as Bremerton Naval Complex (AECOM 2012), underpier areas of Sitcum Waterway, Commencement Bay, Tacoma (Patmont et al. 2004), and other portions of the Commencement Bay site in Tacoma (EPA 1989), and Bellingham Bay (Patmont et al. 2004). MNR alone is unlikely to be effective in the majority of the EW OU due to the high degree of vessel usage present. While some areas may receive sediment deposition that lowers surface sediment concentrations over time and contributes to natural recovery processes, the presence of mixing from propwash in the navigation channel and berthing areas is considered to be a significant factor that would reduce the effectiveness of MNR in the EW. The deeper mixing that can occur from propwash would extend the time to reach acceptable concentrations, potentially to unreasonable timeframes (Section 5).

Other factors that affect MNR include chemical and biological processes. While chemical process, such as absorption to organic chemicals to carbon sources, may assist with natural recovery, biological processes are typically not effective at significantly reducing PCB and metals within a reasonable recovery timeframe (EPA and USACE 2000). As discussed in the Screening Memo (Anchor QEA 2012a), MNR alone would likely have relatively low effectiveness in achieving the RAOs. However, MNR may potentially be effective in localized areas as a component of an alternative with combined remedial technologies—particularly in areas that are net depositional and without deep mixing from propwash. Regardless of whether MNR is selected as a remedial technology in the alternatives, natural recovery processes are an important component to be included in the effectiveness evaluation for each remedial alternative presented in Section 9.

MNR is retained as a potential remedial technology with the above-noted limitations. It has been demonstrated in sediment remediation projects and will be carried forward in developing EW remedial alternatives.

7.2.4 Enhanced Natural Recovery

ENR, while a form of natural recovery, involves placement of a layer of clean material over sediment with relatively low to moderate contaminant concentration levels to expedite the natural recovery process. With ENR, the natural recovery process is accelerated as clean material is mixed with the underlying contaminants from bioturbation or vessel propwash (EPA 2005). As described in EPA (2005), ENR can quickly reduce exposure to contaminants and typically requires less infrastructure than ex situ technologies (e.g., dewatering, treatment, and disposal). ENR placement is intended to speed up burial processes and is not intended to provide complete containment of the underlying contaminated sediments. Monitoring is a component of ENR to document that predicted natural recovery is occurring or to determine whether additional remedial action may be required if ENR does not occur as predicted. ENR is typically performed with clean sand material of low OC content for constructability reasons; however, monitoring information from the EW Phase 1 Removal Action (Windward 2007b, 2008a, 2008b), from other sites in the Duwamish (e.g., Duwamish Diagonal Capping and ENR Areas [AECOM 2012], and the Slip 4 Early Action Area [Integral 2015]) demonstrate that sediments equilibrate to ambient OC concentrations within 1 year due to accumulation of incoming sediment (including OC), benthic recolonization, and biological activity (see Appendix B, Part 5).

In the EW, ENR is technically implementable, as supported by the use of predictive modeling discussed in Section 5, to determine areas where natural processes support the use of natural recovery, enhanced with clean cover placement. Placement of ENR clean cover material can be accomplished using readily available equipment options in all CMAs. ENR placement in most underpier CMAs would be more difficult due to equipment inaccessibility and steep underpier side slopes, impacting the stability of the sand layer. ENR has been approved for remedial actions on many contaminated sediment sites and is considered administratively implementable.

ENR has been shown to be effective at reducing sediment concentrations in CERCLA sites within the Puget Sound, such as Commencement Bay (Tacoma, Washington), Eagle Harbor (Bainbridge Island, Washington), Puget Sound Naval Shipyard (Kitsap County, Washington), and at the Ketchikan Pulp site (Ketchikan, Alaska) (Thompson et al. 2003). Within the EW, ENR could be considered for areas of relatively low to moderate contaminant concentrations that are net depositional or in areas where engineered capping (discussed in Section 7.2.5) would be difficult to implement. ENR's effectiveness may be limited in certain CMAs due to vessel propwash, which could cause significant re-suspension and mixing in areas with frequent vessel usage (e.g., propwash zones 1A, 1B, 2, 4A, and 6 in Figure 5-2). ENR's overall effectiveness is considered to be moderate relative to other remediation technologies due to the greater degree of uncertainty about its performance. During design, the use of engineered aggregate mixes or engineered synthetic products may be considered to ensure stability in specific areas where propwash is a concern, depending on the selected areas where this technology could be employed.

The ENR costs are considered to be low to moderate since this technology involves careful placement of clean cover material, along with monitoring and, potentially, long-term maintenance needs, should monitoring indicate the need to replenish the ENR layer.

For the EW, two types of thin sand cover have been retained for potential application, depending on the purpose and location. These cover layers are described below:

- ENR employed in the Sill Reach (ENR-sill) refers to the placement of sand to increase the rate of natural recovery through natural processes, including burial. For the FS, the ENR-sill layer is assumed to consist of an average placement of 9 inches of sand (6 inches minimum placement), consistent with typical thickness assumptions at other sites, and the hydrodynamics and operational considerations of the location; this area has no vessel traffic and a low scour potential, and the thin layer of sand is expected to undergo biological mixing but not undergo significant resuspension and lateral transport over the long term.
- ENR employed in the navigation channel and adjacent berthing areas (ENR-nav) refers to placement of a thin layer of material designed to accelerate natural recovery and to mitigate the effects of resuspension from vessel scour. For the FS, ENR-nav is assumed to have an average thickness of 18 inches (15 inches minimum) to decrease

the contribution of shallow subsurface contamination on concentrations in the biologically active zone in areas anticipated to have deep sediment mixing.

Section 5.4 describes the principles of mixing and long-term modeling simulations following placement of ENR-sill and ENR-nav. Consistent with these modeling assumptions, the ENR layer is expected to partially mix with underlying sediment. This is in contrast to an isolation cap (Section 7.2.5), which is designed to fully isolate sediments.

While specific assumptions have been developed for use in this FS, the composition of ENR material will depend on location-specific factors evaluated during remedial design. For example, the composition and thickness of ENR placement material may be modified to mitigate scour (e.g., grain size specifications or thickness) or enhance habitat (e.g., habitat mix).

ENR is retained as a potential remedial technology with the above-noted limitations. It has been demonstrated in sediment remediation projects and will be carried forward in developing EW remedial alternatives.

7.2.5 In situ Containment (Capping)

In situ containment refers to the placement of an engineered subaqueous covering or cap of clean material on top of contaminated sediment that will remain in place. A cap would be designed to effectively contain and isolate contaminated sediments from the biologically active surface zone. As described in EPA (2005), in situ caps can quickly reduce exposure to contaminants and typically require less infrastructure than ex situ technologies (e.g., dewatering, treatment, and disposal). Because capping leaves contaminated sediments in place, monitoring is a component of in situ containment to ensure that the cap is stable (i.e., not eroding) and continues to effectively isolate contaminants or sufficiently attenuate contaminant mobility through the cap (EPA 2005).

7.2.5.1 Cap Design

Detailed guidance manuals for in situ containment for contaminated sediments have been developed by USACE and EPA (Palermo et al. 1998a, 1998b). The required minimum cap thickness is based on the physical and chemical characteristics of the contaminated sediments and capping material, groundwater flow rates (i.e., advection), erosion potential from natural or anthropogenic sources (e.g., propwash), potential for bioturbation of the cap from aquatic organisms, potential for consolidation of the cap and underlying sediments (including porewater migration that could occur due to compaction), and operations considerations (Palermo et al. 1998a). Total thickness can include cap layers for bioturbation, habitat, consolidation, erosion, operational considerations, and chemical isolation.

A typical cap thickness of up to 3 feet of clean material has been used at many sites (EPA 2005). However, the EW experiences erosive forces from propwash effects from large container ships and tugboats that use the waterway, which necessitates cap armoring in areas that experience significant propwash forces. For the FS, a conceptual cap thickness of 5 feet is assumed in the EW, consisting of a nominal 2.5-foot chemical isolation layer, 1-foot filter layer, and 1.5-foot armor layer. The surface layer of caps in intertidal areas are expected to contain suitable substrate to support benthic organisms and fish communities. The cap thickness was determined based on propwash and contaminant transport modeling, and is expected to have a design life of more than 100 years (Appendix D). The general cap thickness of 5 feet is appropriate for the FS; however, cap thickness will be determined during remedial design and may be thicker or thinner depending on location-specific considerations and additional analysis.

Appendix D demonstrates the predicted effectiveness of the 2.5-foot isolation layer by modeling the movement of contaminants through the cap from underlying sediments with a one-dimensional groundwater flux model (Lampert and Reible 2009). The analysis showed that PCB breakthrough above the assumed performance goals is not expected to occur in less than 100 years following construction. The analysis also showed that cPAHs behave similarly to PCBs and, therefore, would not exceed similar performance goals. Some minimum OC requirements may be required for cap materials to achieve a cap design life of more than 100 years. Specific areas with high metals concentration (e.g., mercury) may also need to be evaluated during remedial design to address the potential for dissolved metals to migrate through a proposed cap to surface sediment and surface water. Cap material specification would be evaluated during remedial design.

Reactive capping is a technology that typically includes addition of sorptive capacity of the cap, depending on the type of contaminant present, to reduce the flux of contaminants from underlying sediments to shallow porewater and the water column. Use of reactive materials may also be warranted where evaluations of standard capping indicate that a sufficiently thick cap cannot be created to adequately reduce the flux of contaminants over time, which may be due to a variety of reasons singly or in combination, such as the presence of highly mobile contaminants, high rates of groundwater advection, and/or the need to maintain certain water depths for navigation or habitat purposes. As described in EPA (2005), examples of materials used in reactive caps include engineered clay aggregate materials and other reactive/adsorptive materials, such as AC. One example was at the 2012 early action at Slip 4 in the LDW, where AC was incorporated into the sand and gravel chemical isolation layer of the cap and placed with a mechanical clamshell (Schuchardt et al. 2012). Reactive agents (e.g., apatite, AC, and/or organoclay) may also be placed within geotextile layers on the sediment surface as a reactive mat. Reactive mats will be considered as a potential option during remedial design. To date, caps with reactive layers have tended to be used in areas with higher underlying sediment concentrations of highly mobile contaminants. Section 7.2.7.1 provides additional discussion of these principles with respect to in situ treatment through the placement of AC.

7.2.5.2 Cap Material Placement

Capping placement can be accomplished using a number of mechanical and hydraulic methods. Placing sand- and gravel-sized materials in a controlled fashion can be accomplished with a variety of equipment such as:

- Controlled discharge from hopper barges
- Hydraulic pipeline delivery of a sand slurry through a floating spreader box or submerged diffuser
- Physical dispersion of barge stockpile capping materials by dozing, clamming, conveyoring, or hydraulic spraying of stockpiled material off the barge and into the water column
- Mechanically fed tremie tube to contain lateral spread of the cap material until it reaches the bottom of the water column
- Lowering of individual, reactive mat cap segments with a crane or other mechanical equipment

Sand and gravel placement can often be accomplished in more difficult access areas through the use of conveyors or hydraulic pipeline discharge. However, steep side slopes are a critical limitation to cap placement due to the ability of cap material to be placed and stay stable on steep slopes. Placement of an armor layer made of cobbles or rocks is more complicated than sand and gravel placement and requires a greater degree of operator skill to avoid overplacing the rock armor layer or prevent missing areas of required armoring. The placement equipment for rock is typically limited to mechanical equipment since hydraulic pipelines and conveyors are limited as to the size of materials they can effectively transport. Rock placement is also limited on steep slopes. In addition, the installation of reactive mat caps in underpier areas would face multiple technical challenges, including access limitations for construction equipment, need for anchoring on riprap slopes, presence of debris, potential need for armoring due to propwash, and the presence of piles that could result in incomplete mat coverage.

Most of the EW is unrestricted open water, and it is feasible to place an engineered cap in waterway areas that do not have overwater piers. For the underpier CMAs, capping material likely is infeasible to place due to equipment inaccessibility, structural and slope stability impacts from placing added weight, and likely infeasibility of placing a stable cap on steep underpier side slopes, which have been designed to approximate 1.75 horizontal to 1 vertical (1.75H:1V) for Port facilities and 2H:1V for USCG piers. As a comparison, temporary stable slopes for sand and gravel mix underwater are generally limited to slopes of 3H:1V or flatter, or 2.75H:1V or flatter, with careful placement (based on experience, also: NavFac [1986]). For the Sill Reach CMA, capping may be difficult to place due to access issues underneath the existing bridge structures. However, the Sill Reach does not have the steep slopes that are present at the Underpier CMAs.

7.2.5.3 Elevation Requirements

In many areas of the EW, capping would also require some dredging because of the need to maintain federally authorized navigation depths and operational berthing depths. CMAs within the federal navigation channel, berth areas, Slip 27, and Slip 36 have minimum water depths that would need to be maintained. Figure 7-2 shows the authorized and operational navigation elevations in the EW.[84]

In such cases, the final elevation of the top of the placed cap would be below the maintained federal navigation channel elevation or berth operational elevations. In some cases, this may require some dredging to accommodate the maximum cap thickness to avoid overplacing the cap above the channel bottom or berth minimum elevations. The cap elevation requirements and associated extent of dredging will be determined during remedial design, which would also consider cap thickness requirements (as described in Section 7.2.5.1). This FS assumes that the top of a sediment cap would be 4 feet below the maintenance elevation in the navigation channel, which accounts for overdredge, vertical accuracy of the dredge, and an additional buffer for safety. In addition, it is assumed that caps that border the navigation channel will have appropriate buffers to avoid being damaged by maintenance dredging activities. These buffers will be reviewed and discussed with USACE during remedial design stages considering site-specific uses and dredging methodology, authorized channel elevations, and existing operational elevations.

Intertidal and nearshore habitats may be home to diverse communities of fish, birds, mammals, and invertebrate species. Therefore, areas with depths shallower than -10 feet MLLW will be managed in ways that approximately restore current elevations. In these areas, partial dredging would be required prior to cap placement to restore the location to pre-construction conditions.

The FS assumes that source material for isolation capping will be imported from commercial off-site vendors. A possible alternative material sourcing could be dredged materials from Puget Sound maintenance dredging sites. Challenges to beneficial use of this material include the following:

[84] As discussed in Section 2.9.2, USACE completed a draft SHNIP Feasibility Report and Environmental Assessment in August 2016, which includes alternatives for deepening and widening the navigation channel. Because the implementation of the navigation improvement project is uncertain, the assumptions for remedial technologies (e.g., post-capping elevation requirements) are based on current conditions and uses. However, all proposed caps within the EW are also compatible with potential future navigation improvements.

- Determining the suitability of material gradation and contaminant concentrations to meet the defined cap material specifications
- Coordinating contract requirements with the federally procured USACE dredge contract
- Adjusting to mismatched production rates (e.g., maintenance dredged material may be generated at rates much less than, or far exceeding, cap placement rates)
- Accounting for re-handling needs and/or lack of suitable storage for dredged material awaiting beneficial use
- Coordination and timing of projects

7.2.5.4 Summary

Capping is considered an effective remedial technology for all COCs in the EW, especially for highly sorbed contaminants such as PCBs. Capping has been shown to be a reliable and proven technology that has been effective at many CERCLA sites within the Puget Sound, such as Commencement Bay (Tacoma, Washington), Eagle Harbor (Bainbridge Island, Washington), Pacific Sound Resources (Seattle, Washington), Georgia-Pacific Log Pond (Bellingham, Washington), and throughout the United States. Because cap construction can be conducted with relatively little disturbance to in situ contaminated sediment compared to dredging, this technology is considered to have relatively few environmental impacts during construction (partial dredging and capping disturbs more in situ contaminated sediment than capping alone). However, capping buries the existing benthic community, which takes time to recolonize and regain ecological functions following construction, and may require habitat enhancement material in addition to cap material to encourage return of the biota.

Capping is considered a moderate cost technology due to the expense of the materials, installation (especially in complex, multiple-layer caps), and monitoring and maintenance requirements. Capping is retained as a potential remedial technology with the above-noted limitations. It has been demonstrated in sediment remediation projects and will be carried forward in developing EW remedial alternatives.

Although small areas of the EW OU may be capped without preliminary partial dredging and still comply with the elevation constraints described above, most of the EW OU would require partial dredging prior to capping and, therefore, capping is referred to as "partial dredging and capping" in subsequent sections of this FS.

7.2.6 Removal

Mechanical dredging, hydraulic dredging, and excavation using upland-based equipment (dry excavation) are the three representative process options available for removal technologies. Removal may result in the least uncertainty regarding future environmental exposure to contaminants because the contaminants are removed from the aquatic ecosystem and disposed in a controlled environment (EPA 2005), but can: 1) result in release of contaminants (i.e., dissolved or sorbed to suspended sediment particles), which in turn results in short-term water quality impacts from dredging that can increase fish and shellfish tissue concentrations both locally and downcurrent (tidal direction) (Bridges et al. 2010); and 2) disturb the benthic community that must recolonize the biologically active zone and regain ecological functions following remediation. Removal is readily applicable in areas with navigation depth requirements because it does not require material placement (as opposed to capping). However, site restrictions and existing structures can limit the ability to remove all contaminated sediment within the waterway. Removal has been proven to be an effective technology for achieving cleanup goals when used in combination with residuals management[85] (see Section 7.2.6.5) and other BMPs (see Section 7.5.3).

This section discusses the mechanical dredging, hydraulic dredging, and dry excavation process options, as well as dredging considerations in underpier areas and dredge residuals management. Removal requires handling of dredged or excavated sediment, including dewatering, offloading, transport, treatment (if required), and disposal, each of which involves additional costs and the potential for further releases. The full process of removal is often referred to as the "treatment or process train." Sections 7.2.7 and 7.3 discuss treatment technologies and disposal options, respectively.

[85] Residuals management includes placement of a thin clean sediment cover over the dredge residuals as a final step in the remediation process to achieve cleanup levels on the sediment surface post-construction.

7.2.6.1 Mechanical Dredging

Mechanical dredges have been used extensively in the Puget Sound for sediment remediation projects and are widely available. Mechanical dredges are designed to remove sediment at or near in situ density (EPA 2005), though some amount of excess water is typically entrained in the dredge bucket as it closes and is lifted up through the water column. The quantity of water generated using mechanical dredging is orders of magnitude less than that generated with hydraulic dredging. The barge-mounted or land-based crane can use different types of buckets or attachments to dredge or assist with demolition activities. Mechanical dredges are capable of working in difficult-to-access areas and are relatively easy to relocate, thus reducing the potential impact to existing site operations. Environmental buckets can be used in the appropriate sediment conditions to help limit sediment resuspension during bucket retrieval (see Section 7.5.3.1).

A typical "treatment or process train" for mechanical dredging (assuming landfill disposal) assumed for this FS is listed below:

- Dredge contaminated sediment
- Place contaminated sediment in a haul barge
- Dewater on the barge (treatment by filtering or any active measures to meet water quality criteria at the point of compliance)
- Transport contaminated sediment to either an on-site or off-site offloading/staging area
- Offload sediment to a stockpile area
- Treat effluent from the stockpile and discharge to receiving waters or approved publically owned treatment works (POTW)
- Transport contaminated sediment over land by truck or rail
- Dispose contaminated sediment at a landfill facility

Mechanical dredging is considered feasible for open-water areas because of its effective removal of consolidated sediment, debris, and other materials such as piling and riprap and its ability to relocate, thus reducing the potential impact to existing site operations. In underpier areas, mechanical dredging would be infeasible due to equipment inaccessibility.

Some applications of mechanical dredging in shallow water environments have been performed with increased positional control over the dredge bucket when using a fixed arm (as opposed to a cable arm). This method has been employed at the Plant 2 Early Action Area in the LDW. However, this method would only be applicable for nearshore areas in the EW OU, and not the majority of the waterway due to deep water depths.

7.2.6.2 Hydraulic Dredging

Hydraulic dredging typically involves using a cutterhead or similar equipment to slurry sediment in the water column and siphon the slurry into a pipe. Hydraulically dredged material can be transported via piping directly to a staging/processing area. The hydraulic transport pipeline is typically a floating pipeline, which can interfere with vessel navigation. Relative to mechanical dredging, a significantly greater volume of water is entrained with the sediment slurry removed by the dredge and must be subsequently separated from the sediment solids and treated and discharged (EPA 2005). The solids content of hydraulically dredged slurries typically averages about 10% by weight, but it can vary considerably with the specific gravity, grain size, and distribution of the sediment, and depth and thickness of the dredge cut. In general, hydraulic dredges cannot remove rocks and debris. Hydraulic dredging has been implemented at many contaminated sediment sites, although hydraulic dredging has been used much less frequently than mechanical dredging at sediment remediation sites in Puget Sound.

Dewatering of hydraulically dredged sediments is required prior to upland transport and disposal. Hydraulically dredged sediments can be dewatered using passive or active methods and typically requires use of large settling basins due to the relatively large volume of water in the resulting slurry collected. Dewatering requires an upland staging area, usually in close proximity to the dredge area due to the difficulties in placing, operating, and maintaining long distances of pipeline over water and land. The EW OU has limited space in the upland area close to the EW that is not already under a long-term lease. Hydraulic dredging has been retained only for underpier areas.

7.2.6.3 Underpier Dredging

Removing contaminated sediment from underpier locations presents significant engineering and construction challenges. Dredging must be accomplished working around existing structures. However, removals require coordination with the owner. Riprap slopes are often constructed in underpier areas to provide slope stabilization or wave and propwash protection purposes, and contaminated sediment fills in the interstices of the riprap, making it impossible to remove all of the contaminated sediment using dredging methods.

The feasibility of underpier dredging is dependent upon the pier design (e.g., pile spacing, deck elevation, and other obstructions), presence of debris and broken-off piling, underpier slope geotechnical conditions, and ability of equipment to access the underpier area without potentially damaging the existing structure. Few examples of diver-assisted hydraulic dredging are available that removed contaminated sediment located under piers on smaller projects (e.g., Esquimalt Graving Dock, Victoria, British Columbia, 2013-2014; Sitcum Waterway Remediation, Tacoma, Washington, 1995). However, diver-assisted dredging has significant issues including extremely low production rates, inability to remove consolidated sediment, inability to remove debris, and safety concerns. Specifically, the risks for injury and death during construction increase with every hour divers would need to be assisting hydraulic dredge activities. This risk is weighed against long-term risk of leaving contaminated sediment in the underpier areas (Section 9.1). Underpier hydraulic dredging has the same considerations as standard hydraulic dredging, such as use of a hydraulic pipeline, extensive water management needs, and the need to dewater the sediment, but with significant additional technical and safety challenges. Diver-assisted hydraulic dredging is retained for further consideration in underpier areas, despite the drawbacks discussed above. Design criteria would be developed during the design phase if this technology is selected.

In summary, the site conditions for underpier diver-assisted hydraulic dredging include the following:

- Sediment removal from steep slopes (1.75H:1V in most areas) composed of large riprap and difficult-to-reach interstices.

- Work conducted in deep water, limiting dive time for each diver and potentially requiring the use of decompression chambers (as required by commercial diving regulations), resulting in a large team of divers to complete the work and making the work more hazardous from a worker health and safety perspective.
- Low visibility because of shade from the pier, water depth, and sediments suspended as part of the work, making the work more hazardous from a worker health and safety perspective.
- Debris, such as cables, large wood, and broken pilings, making dredging more difficult and potentially more unsafe.
- Presence of infrastructure, such as existing piling and cross bracing, which will require relocation of both floating and submerged lines into and out of each row of piles.
- Generation of large quantities of water that must be treated prior to discharge back to the waterway. Upland areas are not typically available for slurry storage, sediment settling, effluent treatment, testing, and discharge because of Port operations at existing terminals, and pipeline transport of the slurry to an upland staging location is not feasible because of the interference with navigation. Therefore, it is most likely that the sediment slurry will need to be handled using a portable treatment system on a barge, which complicates the water containment, dewatering, and treatment, and could limit the daily production rate.
- Underpier areas adjacent to active berthing areas, which average around 300 container ships per year and 600 total vessel calls per year in the EW. Diving schedules are likely to be significantly impacted by waterway activities, which could result in delays in completing the work. In particular, dive time may be further limited due to risks posed to divers from propwash and suction forces from transiting and berthing container ships. Similarly, more business interruption will occur as a result of hydraulic dredging because of restricted access to areas where divers are performing underwater work.

Mechanical underpier dredging is not retained for further consideration because it may pose unacceptable risks for damaging the existing structures or underpier riprap slopes and environmental concerns associated with sediment resuspension as a result of dragging sediment from the underpier area downslope into the toe of slope where additional equipment can be used to re-dredge the sediment and lift it to a haul barge.

7.2.6.4 Dry Excavation

Sediment excavation involves the use of excavators, backhoes, and other conventional earth-moving equipment to remove contaminated sediment from exposed sediment areas (e.g., not submerged). This is particularly pertinent in portions of the EW where equipment could conduct dry excavation in shoreline or intertidal areas during low tide.

Dry excavation can also be conducted by diverting or draining water. Diversion of water from the excavation area can be facilitated through the installation of temporary cofferdams, sheetpiling, or other water management structures and the subsequent lowering of the surface water elevation within the excavation area. Following dewatering of the area, equipment can be positioned on the bed within the excavation area or immediately adjacent to the dewatered excavation area. Diversion tends to be generally limited to localized areas with high sediment concentrations. These temporary structures could disturb buried subsurface contamination and could result in releases when removed. During remedial design, engineering evaluations would be conducted to determine appropriate methods of diverting water in areas where this process option is necessary and feasible.

7.2.6.5 Dredge Residuals

All dredging projects result in some degree of re-suspension, release, and residuals (NRC 2007). Dredging residuals include undisturbed residuals (or missed inventory), which is contaminated sediment that remains un-dredged due to the inability to be 100% accurate in delineating all of the contaminated sediment. The quantity of missed inventory can be minimized through sampling conducted as part of remedial design. Residuals also includes generated residuals, which are contaminated sediment re-suspended during dredging, due to removal equipment limitations in preventing loss of particulate and dissolved material. The particulate material that settles is the generated residuals. The need to address dredging residual contamination depends upon the concentrations and thicknesses of residuals remaining. However, empirical data from numerous sediment remediation projects indicate that residual contamination is a common occurrence and that sites are unlikely to achieve their RAOs with dredge technology alone (Patmont and Palermo 2007; NRC 2007).

Research has shown that residual sediment remaining on the post-dredge surface (typically ranging from 2% to 11% of the remaining contaminated sediment mass prior to the final production dredge pass) have been observed during most environmental dredging projects (Desrosiers and Patmont 2009). The relatively deep water depths in the EW increase the likelihood of generating dredge residuals, which could spread to adjacent unremediated areas as a result of vessel propwash, since remediation would be conducted in an active waterway over multiple construction seasons.

Common approaches to managing dredging residuals are discussed in detail in Appendix B, Part 5. The final residuals management approach decision framework will be developed during remedial design. Once the residuals management decision framework is developed, post-dredging monitoring data will be used to determine if and what residuals management contingency actions are needed to meet the dredging performance goals. Residuals management contingency actions may include natural recovery, placement of RMC, or re-dredging.

RMC refers to the placement of approximately 4 to 12 inches of sand following dredging, to reduce the impact of dredging residuals on surface sediment concentrations, as needed, in open-water dredging areas (see Section 7.2.6.5). RMC, like ENR, is generally assumed to mix with shallow subsurface sediment and incoming sediment as a result of bioturbation and vessel propwash in scour areas. Recent sediment remediation project designs include placing a residuals cover as either the primary or secondary residuals management technology (e.g., LDW Slip 4 Early Action Area, East Waterway Phase 1 Removal Action, Port of Olympia Berths 2 and 3 Interim Action, Port Gamble Wood Waste Removal, and Denny Way Interim Action). Placement of RMC may be limited by site conditions, such as inability to place on steep slopes. The physical placement of RMC could resuspend and disperse fine-grained residuals. RMC is typically used as a contingency action if post-remediation surface sediment concentrations exceed a set threshold; the need, extent, and thickness of the RMC would be determined following post-removal sampling. Similar to ENR, RMC is typically performed with clean sand material of low OC content for constructability reasons. As discussed in

Section 7.2.4 and Appendix B, Part 5, sediments are expected to equilibrate to ambient OC concentrations within 1 year due to accumulation of incoming sediment (including OC), benthic recolonization, and biological activity.

As discussed in Appendix B, Part 5, RMC is considered a cost-effective method for achieving post-dredging performance goals, and is therefore likely to be used in the EW following dredging. For this FS, it has been conservatively assumed for costing purposes that RMC will be placed in all open-water dredged areas and in areas adjacent to dredged areas where dredge residuals may be redistributed and result in elevated concentrations (i.e., interior unremediated areas). RMC would be placed by spraying, by a spreader, or by spreader barge with a conveyor and sand box, similar to placement of ENR.

7.2.6.6 Summary

Dredging is a proven and reliable remedial technology and suitable for use in the EW when used in combination with residuals management. Dredging does result in release of contaminants (i.e., dissolved or sorbed to suspended sediment particles) to the water column during construction, and potential sediment transport will likely result in water quality impacts during dredging even if all dredging BMPs are used.

For the FS, mechanical dredging is retained in all areas except under piers. Hydraulic dredging is retained in underpier areas, but has significant safety issues as well as design and construction issues due to technical feasibility, water management issues, equipment (i.e., floating pipeline), and impacts to navigation. Dry excavation may be employed in shoreline areas, including the Sill Reach, subject to further evaluation during design. Dredging near structures may need to be restricted to avoid adversely impacting their stability. Dredging may also be used in conjunction with capping to meet elevation restrictions.

7.2.7 Treatment Technologies

Treatment technologies refer to chemical, physical, and biological process options that can be applied to contaminated sediment, either in situ or ex situ, to reduce concentrations, immobilize the contaminants, or reduce bioavailability of contaminants to biota. Treatment technologies have been reviewed as part of the LDW RI/FS and included in the LDW memo

(RETEC 2005), as well as in Tetra Tech (2010). These previous treatment evaluations were presented in the Screening Memo (Anchor QEA 2012a) and have been accepted by EPA Region 10, and are relevant to the EW based on proximity of the sites to each other, similar site conditions, and similar COCs. This section presents in situ and ex situ treatment technologies retained for consideration in the FS.

7.2.7.1 In Situ Treatment

In situ sediment treatment technologies include sequestering agents (e.g., AC), biological or chemical degradation, immobilization, and other potentially appropriate treatment technologies to reduce levels or mobility of sediment contaminants while leaving sediments in place. For the EW, sediment amendments have been retained for further consideration. EPA has recently supported in situ application of amendments as an in situ treatment and is overseeing a pilot study on the use of AC in the LDW. AC has been demonstrated to reduce the bioavailability of several contaminants, including PAHs, PCBs, dioxins/furans, DDT, and mercury, when directly mixed into sediment (EPA 2011; Ghosh et al. 2011). AC has been added as an amendment to both sand cover and bentonite (Cornelissen et al. 2011a; Oen and Cornelissen 2010; Oen et al. 2011). Another type of amendment used as an in situ treatment includes addition of organoclay to reduce the bioavailability for non-soluble organics and potentially other contaminants (Sarkar et al. 2000). This type of in situ treatment is most applicable to sediment in the biologically active zone (i.e., approximately the upper 10 cm of sediment). A different form of in situ remediation, in situ bio-enhancement, is a technology that is being explored by researchers but has not been retained in this FS.

Considering the range of COCs identified in EW, in situ sediment treatment is a potential remedial technology. Recent data from Bremerton Naval Shipyard indicate that in situ treatment can reduce bioavailability of PCBs in Puget Sound sediments (Chadwick et al. 2014). Patmont (2013) identified 19 sites worldwide where AC or biochar materials have been used for the in situ treatment of contaminated sediments. The AC process option has been demonstrated to be effective in the short term (limited long-term data are available) for organic contaminants at several remediation project sites including the Grasse River in Massena, New York (Ghosh 2010; Alcoa 2010), Hunter's Point Naval Shipyard in San Francisco, California (Luthy et al. 2009; Cho et al. 2009; Janssen et al. 2009, 2011), Aberdeen

Proving Ground in Maryland (Menzie 2011a, 2011b), U.S. Army Installation in Virginia (Menzie 2011a, 2011b), and at several sites in Norway (Oen and Cornelissen 2010; Oen et al. 2011). Successful AC placement has occurred at these sites using rotary tilling, injection, broadcasting, and with a "tine sled" device that directly injected AC into near-surface sediment. At the sites in Norway, pre-mixing AC with another medium (e.g., sand) prior to placement was found to accelerate the natural bioturbation process, resulting in a more homogeneous long-term application of AC when placed in shallow water depths or in the "dry" (Oen and Cornelissen 2010; Oen et al. 2011).

Since AC is a low density, lightweight material, it is typically blended with other traditional sediment materials such as silts, sands, or dredged material from nearby waterways to generate a material that will sink to the bottom of the area to be treated. Several proprietary products have been developed that combine the AC with a heavier core particle and other binding agents to produce a particulate material that can be placed like a soil or sediment. Examples of the latter material include Sedimite™ and AquaGate+PAC™.

The design life of specific amendments would be evaluated during remedial design, and will vary based on the targeted contaminants, source and type of amendment, amount of amendment used (i.e., design safety factor), and the potential need for replenishment. Physical stability and chemical activity (e.g., adsorption capacity) over the long term are the most important design life factors. AC and other charcoals created under high-temperature conditions are known to persist for thousands of years in soils and sediments, and laboratory studies and modeling evaluation both indicate promising long-term physical stability of the amendment material and chemical permanence of the remedy (Ghosh et al. 2011).

Underpier areas are identified for in situ treatment under some remedial alternatives to reduce bioavailability. Location-specific factors will be evaluated during remedial design, especially related to type and amount of the amendment and habitat considerations.

In situ Treatment Effectiveness Assumptions

For the purpose of modeling, this FS estimates that in situ treatment will reduce bioavailability of total PCBs, cPAHs, and dioxins/furans by 70%. This is on the low end of values measured in the field and laboratory when applying an AC dose between 3% and 5%.

EPA (2013) concluded that, "...adsorption of hydrophobic organic contaminants (HOCs) to AC in sediments is often 10 to 100 times greater than absorption to organic carbon (OC)," indicating a percent reduction between 90% and 99%. A bioavailability reduction of 70% has been selected for these EW site conditions in coordination with EPA, considering EW-specific conditions, including the potential for burial, mixing, and loss of AC material from propwash forces.

Recent field pilot studies indicate that a 70% reduction in bioavailability is at the low end of measured values for PCBs and other hydrophobic contaminants. Chadwick et al. (2014) found that total PCB concentrations in underpier areas at the Bremerton Naval Shipyard decreased by 90% in porewater and 80% in bioaccumulation test organisms in nine sample stations 10 months following application of AC. Beckingham and Ghosh (2011) found that bioaccumulation of PCBs in worms was reduced between 69% and 99%, and concentrations in porewater were reduced by greater than 93% in 3 years following AC amendment of river sediments. A pilot study in Trondheim Harbor also indicated that approximately 90% reduction in bioavailability can be achieved for PCBs and PAHs with variations based on the matrix of delivery (i.e., AC with sand versus AC with clay versus only AC; Cornelissen et al. 2011b).

Review of laboratory studies also indicates that 70% reduction in bioavailability is at the low end of measured values for PCBs and other hydrophobic contaminants. Ghosh et al. (2011) summarized a number of laboratory demonstrations, concluding that laboratory "...tests with a range of field sediments showed that AC amendment in the range of 1-5% reduces equilibrium porewater concentration of total PCBs, PAHs, DDT, and dioxins/furans in the range of 70% to 99%, thus reducing the driving force for the diffusive flux of hydrophobic organic compounds into the water column and transfer into organisms."

Based on these studies, this FS estimates that an appropriate in situ treatment material could be selected and engineered to reduce bioavailability of PCBs by 70% in underpier sediments of the EW, which is approximately in the low end of the range of empirical studies and at the low range of EPA guidance (EPA 2013). While any hydrophobic organic contaminant that comes into contact with in situ treatment material is expected to very quickly result in reduction of bioavailability, the low end of the range was selected due to frequent vessel traffic and high propwash forces in the EW, which could result in the resuspension and distribution of AC material and therefore reduce effectiveness. However, in situ treatment is an evolving remedial technology with new information available every year. Bioavailability assumptions may be refined based on additional data that may soon become available, such as additional monitoring data from the underpier in situ treatment area at the Bremerton Naval Shipyard, which may be pertinent to EW evaluations.

Underpier Material Placement

Access to the sediments in underpier areas would be difficult, due the presence of the supporting piles and the low overhead clearance under the pier deck surfaces. The use of traditional marine-based dredging or barge-mounted placement equipment is precluded due to these access restrictions. Since the primary in situ treatment technology being considered for use in the EW relies on the placement of particulate material containing AC, these access restrictions will determine the methods for placement.

All of the available AC-containing materials fundamentally require the handling of a bulk material from a stockpile and subsequent placement at the required amount per surface area on the sediments to be treated. Methods for moving these materials into confined places such as the underpier areas may be limited to specialized equipment and placement methods, such as long-reach conveyors like a Telebelt™ system and hydraulic or pneumatic pumping and placement. The FS assumes that selection of a remedial technology for placement of in situ treatment will occur during remedial design; for costing purposes, the FS assumes use of a Telebelt conveyor. Each of these methods are briefly described below.

Telebelt™ – The Telebelt is a telescopic belt conveyor that has been used at sediment remediation sites (e.g., Bremerton Naval Shipyard) for the placement of a variety of capping and AC treatment materials. The systems are truck-mounted or trailered, can be placed on a barge, and can extend to reach up to 200 feet, depending on the ability to properly deploy the outrigger system and the weight of the materials to be conveyed. When used to place AC amendment, the system can be placed on a barge alongside the pier being remediated. The conveyor can be extended horizontally under the pier between each row of pilings. The conveyor speed is regulated along with the arm movement to place a known amount of material over the target area.

Hydraulic Pumping – In the hydraulic pumping method, the AC-containing materials are mixed with site water to form a slurry that can be pumped to the sediment area to be treated. When used in an underpier setting, divers are most often used to control the discharge lines and place the material. This system allows for control of the material placement and coverage thickness, but is labor intensive and is a slow process. The slurried material is also susceptible to flowing down any slopes, more so than a granular material being placed through the water column. The slurrying process can also introduce difficulties in maintaining a consistent AC dosage when a blended material is being used due to separation during mixing and placement, although many sites have overcome these potential difficulties.

Pneumatic Pumping – Materials such as the Sedimite™ product have a low enough density that they have been successfully placed using pneumatic blower systems. These applications have primarily been in wetland situations where backpack-mounted blowers are used to place relatively small volumes of material. In an underpier application, a pneumatic system potentially could be used to deliver a similar type of product using divers or personnel in small boats operating in the inter-piling areas to control the discharge end of the pump line. Placement with this method would be considered a slow process, and a granular material that is light enough to move pneumatically may not settle quickly and efficiently through a deeper water column.

Ex situ Treatment

Ex situ treatment refers to technologies that immobilize, transform, or destroy COCs after first removing contaminated sediment from the site. For the EW, the separation, or soil washing, ex situ treatment process option has been retained for further consideration. This option uses conventional and readily available material handling unit processes to separate sediment particles, typically into coarse (sand and gravel) and fines (silt and clay) fractions. These equipment systems include screening, gravity settling, flotation, and hydraulic classification (e.g., using hydrocyclones) (USACE-DOER 2000). Soil washing is a wet process and therefore, generates wastewater that requires treatment and discharge. Depending on site conditions, the washed coarse fraction may be suitable for in-water placement (see Section 7.3.3 for beneficial uses of sediment) as a cap, ENR, or habitat creation/restoration medium. However, the treated sediment to be used as placement material would be subject to physical and chemical testing to confirm suitability in meeting the specification requirements (material gradation and chemical concentrations) for use at the site, and therefore, be accepted as "clean" material. The fines fraction, which has higher concentrations of contaminants, is typically dewatered, transported, and disposed of in a permitted upland landfill. Ideally, the net outcome of soil washing is a reusable coarse fraction and a reduced volume of contaminated material requiring additional treatment or direct disposal.

A small percentage of sediments in portions of the EW may be sufficiently coarse-grained to consider soil washing as a potentially viable treatment. One vendor has indicated that soil washing has the potential to be economical where the sediment contains greater than 30% sand (Boskalis-Dolman 2006). When the sediment contains less than 30% sand, treatment performance and economics deteriorate. Ex situ treatment by soil washing was retained for evaluation in the Screening Memo (Anchor QEA 2012a); however, ex situ treatment is not carried forward as part of the remedial alternatives in this FS. Soil washing has been eliminated from consideration at other recent sites (LDW Record of Decision [EPA 2014]). It could also be part of any of the remedial alternatives presented in Section 8 and would not affect the effectiveness of in-water remediation. Additional evaluation may be considered during remedial design to assess whether adding this ex situ treatment process option to the overall removal "treatment or process train" helps to reduce overall remediation costs.

7.2.7.2 Summary

In situ treatment, specifically the placement of amendments such as AC, has been retained for evaluation in the development of alternatives. None of the ex situ treatment options have been retained.

7.3 Preliminary Disposal Technologies

Several disposal options for dredged sediment were identified in the Screening Memo (Anchor QEA 2012a) and are summarized here for applicability for cleanup in the EW, including confined aquatic disposal (CAD), nearshore confined disposal facilities (NCDFs), upland disposal sites, beneficial use of SMS-suitable dredged material, upland commercial landfill options, and disposal of sediments at the DMMP open-water disposal site in Elliott Bay.

Each of these disposal technologies was evaluated in the Screening Memo for implementability, effectiveness, and cost (Anchor QEA 2012a). Based on that evaluation, only upland landfill disposal was determined to be a viable disposal technology for consideration in the FS. However, each of the disposal technologies listed here are summarized below in the event that specific implementability or effectiveness considerations change that could make them viable disposal options during the remedial design period.

Off-site disposal of dredged sediment from a CERCLA site must be consistent with the Off-Site Rule (40 CFR 200.440). The purpose of the Off-Site Rule is to avoid having CERCLA wastes from response actions authorized or funded under CERCLA contribute to present or future environmental problems by directing these wastes to disposal areas determined to be environmentally sound. It requires that CERCLA wastes may only be placed in a facility operating in compliance with RCRA or other applicable federal or state requirements. The Off-Site Rule establishes the criteria and procedures for determining whether facilities are acceptable for the receipt of CERCLA wastes from response actions authorized or funded under CERCLA. For disposal options discussed in this section, any sediment taken outside of the EW OU study boundary for disposal purposes must comply with the Off-Site Rule. Each of the off-site disposal technologies, including off-site CAD, NCDF, and upland landfill, are expected to be reviewed by EPA in the context of this rule. As discussed in the Workplan (Anchor and Windward 2007), off-site aquatic disposal technologies are evaluated within the general bounds of the Duwamish River, EW, WW, and Elliott Bay.

7.3.1 Aquatic Disposal

7.3.1.1 Confined Aquatic Disposal

CAD is a type of underwater sediment disposal that includes some form of lateral confinement (e.g., placement in natural or excavated bottom depressions or behind constructed berms) to minimize spread of the materials on the bottom. A cap of clean material is used to isolate the marine environment from the contaminated sediment and prevent contaminant mobility through the cap.

A potential CAD alternative within the EW was not retained because a number of considerations and limitations make it logistically challenging and likely technically and administratively infeasible. These considerations include the presence of an active waterway with frequent ship traffic, a federally authorized navigation channel, the communication cable crossing in the vicinity of Station 1700, geotechnical stability to support a CAD site, and structural considerations that limit the extents of the CAD site along the east and west sides of the waterway.

In addition to the on-site CAD option, off-site CAD options have been evaluated as part of the Multi-User Disposal Site (MUDS) program (USACE et al. 1999) and LDW FS (AECOM 2012). A number of CAD sites have been constructed in Puget Sound, including one constructed in 1984 in the WW (Sumeri 1984, 1989; USACE 1994), which was demonstrated to effectively isolate contaminated sediment (USACE et al. 1999).

Use of an off-site CAD site is considered to have significant administrative implementability challenges from the standpoints of siting, constructing, and maintaining a CAD facility. Challenges include obtaining agreement from the landowner(s), monitoring and maintenance needs, and enforcing institutional controls on activities above and adjacent to the CAD site (e.g., restricting anchoring and limiting navigation). Land within the EW and surrounding waterbodies may be state-owned and managed by DNR. DNR policy states that it will not allow any contaminated sediment to be placed on state-owned land.

Due to the difficulties in implementation, the CAD disposal technology is not retained for further consideration in alternative development in the FS. However, a CAD disposal technology may be reconsidered during remedial design if the adverse implementability considerations change.

7.3.1.2 Nearshore Confined Disposal Facility

A NCDF consists of berms, cofferdams, or similar structures that create a contained disposal area for dredged materials. NCDFs provide for permanent storage of dredged sediments. Containment of contaminated sediments in NCDFs is generally viewed as a cost-effective remedial technology at Superfund sites (EPA 1996). NCDFs have been constructed throughout Puget Sound, including in the Milwaukee Waterway in Tacoma, the Eagle Harbor East Operable Unit in Winslow, T-90/91 in Elliott Bay, Pier 1-3 in Everett, and Slip 1 in the Blair Waterway in Tacoma. Within the EW, Slip 27 and Slip 36 have previously been evaluated for the use of this technology.

As part of the EW Deepening Project in 2000 (Anchor 2000), the options of using Slip 27 and Slip 36 as NCDFs were evaluated. Each alternative consisted of using the entire capacity of either slip by constructing a containment berm (closure dike) across the mouth of the slip. Development of Slip 27 as a NCDF would require demolition of existing Pier 28, and development of Slip 36 as a NCDF would require demolition of existing USCG and Port structures, including existing timber and concrete piles, timber and concrete apron, and timber fender piles along Pier 36, the Pier 36 apron, and Pier 37. Contaminated dredged sediment would then be placed within the confined slip up to elevation +9.0 feet MLLW to keep the contaminated sediment at or below groundwater level, which would help to reduce leaching of the contaminants, and a sand cap would be placed to elevation +16.0 feet MLLW.

Off-site NCDF locations were considered within Elliott Bay as part of the MUDS program, and only one conceptual site using the northern shoreline of T-5 was identified and evaluated. Similar to CAD options evaluated in Elliott Bay, no further evaluations of NCDF options have occurred as part of the MUDS program. However, as part of the EW Deepening Project in 2000 (Anchor 2000), the option of using T-5 as a NCDF was re-evaluated. The footprint of this conceptual NCDF is located within the Lockheed West Superfund Site and consists of construction of a three-sided containment berm extending out from the existing shoreline, placement of the project's dredged sediments unsuitable for open-water disposal, and placement of capping materials. The conceptual design would accommodate a storage capacity of 320,000 cy of unsuitable sediment. The T-5 CDF concept was also intended to provide intertidal habitat on the cap surface.

The estimated capacity of the Slip 27, Slip 36, and T-5 NCDFs would be less than the conceptual total volume of contaminated sediment within EW. Many administrative implementability issues are associated with NCDFs, including the presence of state-owned aquatic land at part of each location. DNR owns most of the aquatic lands in the EW and has a policy against placing contaminated sediment on Washington aquatic lands. For Slip 27, another major impediment is a previous agreement developed between the Port and the Muckleshoot Tribe in which the Port agreed to provide a conservation easement that no future pier or moorage improvements will be constructed along the south shoreline of Slip 27 (Muckleshoot Indian Tribe and Port of Seattle 2006). In order to use Slip 36 as a NCDF, USCG facilities would need to be relocated and the land acquired from the federal government. In addition, the EW is a Tribal U&A fishing area, including both slips. Creating a NCDF within the EW would impact U&A fishing and approval may be difficult to obtain. NCDF is therefore not retained for further consideration in this FS.

7.3.1.3 Open-water Disposal

Open-water disposal consists of disposal of sediments at the DMMP unconfined, open-water disposal site in Elliott Bay. This disposal technology would require approval from the DMMP agencies, which include EPA. To be suitable for open-water disposal, sediment must meet screening criteria that is based on chemistry, bioassay, and bioaccumulation testing. It is anticipated that all or nearly all of the sediments required to be removed from the EW because of sediment contamination will not be suitable for open-water disposal. Open-water disposal is not retained for detailed analysis in the FS; however, open-water disposal may be reconsidered during remedial design if there are portions of the EW that are determined to be suitable for DMMP open-water disposal.

7.3.2 Upland Disposal

Dredged sediment can be disposed of off-site at an upland waste disposal facility. Dredged material that satisfies the solid waste regulations could be disposed of in Subtitle D RCRA commercial landfills. Sediments removed from the EW are not expected to require disposal in a landfill permitted to receive RCRA hazardous waste or Toxic Substances Control Act (TSCA) waste (i.e., Subtitle C landfill). The Roosevelt Regional Landfill is operated by Allied Waste in Roosevelt, Washington; the Columbia Ridge Landfill is operated by Waste Management near Arlington, Oregon; and the Weyerhaeuser Landfill at Castle Rock, Washington, are three upland regional landfills that have established services to receive wet sediments. Both have the ability to receive wet dredged sediments delivered to the landfill by rail. One additional landfill, the Greater Wenatchee Regional Landfill in Wenatchee, Washington, requires that the sediment be dewatered so that it will pass the paint filter test for free water prior to accepting the sediment. Disposal at this landfill requires dewatering of sediments for both transport and disposal of the dredged material, which would require a dewatering facility at the point where wet sediments are offloaded from the haul barge to shore. Landfills may elect to use sediment as daily landfill cover; however, this is not considered "beneficial use" because the sediment still requires transport to and tipping at the landfill.

Each of these Subtitle D landfills are retained as representative disposal process options for remedial alternatives that call for sediment removal with disposal in an upland landfill.

7.3.3 Beneficial Use

Beneficial use includes in-water and upland placement of dredged material. Aquatic placement includes use of the sediment as capping material, residual management, or habitat creation. Upland beneficial use could potentially include using the untreated or treated sediment as fill, composting it, or blending it with other humic materials, and selling it as a commercial soil mixture. The physical properties of the treated material may limit its applicability to some of these potential use options.

Beneficial use is technically implementable at the EW, but would only apply to untreated or treated sediment that is below unrestricted state cleanup levels or open-water disposal criteria, which is generally accepted to be "clean" sediment. No EW sediments dredged during cleanup are expected to be below criteria that would allow beneficial reuse as fill material unless treated. In addition, sediment removed from within a CERCLA site is generally not suitable for direct beneficial use applications because of the liability associated with using contaminated material.

For contaminated sediments dredged as part of a cleanup action, treatment would be required before possible beneficial use. The coarser (sand) product (processed material achieving target levels established for the project) from a soil washing process could potentially be reused within the EW for capping, habitat or wetland restoration, or grade restoration (i.e., to meet final bathymetry requirements) as part of the remedial action. However, a review of existing literature and local knowledge did not identify any examples of treated sediments being beneficially used in the Puget Sound region.

The sand produced from a soil washing process could also be reused in the uplands as construction fill or as material feedstock for other industrial or manufacturing applications (e.g., concrete or asphalt manufacture, or compost). Depending on the end use and associated exposure potential, it is not known whether the treated sand fraction would achieve appropriate chemical criteria for all contaminants. Upland beneficial use would also require resolution of legal issues related to material classification, antidegradation, and potential liability. In-water and upland beneficial use is not retained for detailed analysis in the FS; however, beneficial use may be reconsidered during remedial design if there are portions of the EW that are determined to be suitable in the future.

7.4 Monitoring

Monitoring is an important assessment and evaluation tool for collecting data and is a requirement of remedial alternatives conducted under CERCLA. Monitoring data are collected and used to assess the completeness of remedy implementation, remedy effectiveness, and the need for contingency actions. The sampling and testing process options considered at most sediment remediation projects include one or more of the following:

- Sediment quality (e.g., chemistry, grain size distribution)
- Sediment toxicity
- Surface water quality (e.g., conventional parameters and contaminant concentrations)
- Contaminant concentrations in porewater
- Contaminant concentrations in fish and shellfish tissue
- Physical (e.g., visual inspections and bathymetry)

Typically, these sampling and testing process options are prescribed components of project monitoring plans which, in turn, focus on different aspects of the remedial action. For example, monitoring during the construction phase has different objectives than the operation and maintenance (O&M) monitoring that follows construction. Five different monitoring concepts that form the basis for individual or combined monitoring plans, depending on project-specific circumstances, are described below. Appendix G provides the rationale and conceptual structure for a multi-component EW OU monitoring program.

7.4.1 Pre-construction Baseline Monitoring

Baseline monitoring establishes a statistical basis for comparing physical and chemical site conditions prior to, during, and after completion of a cleanup action. Baseline monitoring for the EW could entail the sampling and analysis of sediment, surface water, or tissue samples in accordance with a sampling design that enables such a statistical comparison of conditions.

7.4.2 Construction Monitoring

Construction monitoring during construction activities is area-specific and short-term and is used to evaluate whether the project is being constructed in accordance with plans and specifications (i.e., performance of contractor, equipment, and environmental controls). This type of monitoring evaluates water quality in the vicinity of the construction operations to determine whether contaminant re-suspension and dispersion are adequately controlled. Further, bathymetric monitoring data establish actual dredge prisms or the placement location and thickness of cap material.

7.4.3 Confirmational Sampling

Confirmational sampling is performed at the conclusion of in-water construction and evaluates post-construction sediment conditions. Both chemical and physical data are collected to determine whether the work complies with project specifications.

7.4.4 Operations and Maintenance Monitoring

O&M monitoring refers to data collection for the purpose of tracking the technology performance, long-term effectiveness, and stability of individual sediment cleanup areas. In capping areas, O&M monitoring typically consists of analysis including COCs, grain size, TOC, and cap thickness using sediment or porewater matrices. A combination of tools, including bathymetry soundings, surface grab samples, sediment cores, diver surveys, peepers, staking, and/or settlement plates is used to evaluate cap performance. Some of these tools are also used for ENR and MNR performance monitoring.

7.4.5 Long-term Monitoring

Long-term monitoring evaluates sediment, tissue, or water quality at the site for an extended period following the remedial action to assess risk reduction and progress toward achievement of RAOs. Data collected under long-term monitoring yields information reflecting the combined actions of sediment remediation and source control.

7.4.6 Monitoring Summary

Monitoring is an essential element of remedial alternatives developed in this FS. Appendix G sets forth key assumptions and an overall framework for monitoring using the process options and monitoring objectives described above.

7.5 Ancillary Technologies

Ancillary technologies include dewatering, wastewater treatment, and BMPs. These technologies offer important considerations in the assembly of remedial alternatives.

7.5.1 Dewatering

After removal, dredged sediment may be managed in a number of ways as discussed in Section 7.3. Prior to re-handling, transport, ex situ treatment, or disposal, the dredged sediment may require dewatering to reduce the sediment water content. Dewatering technologies may be used to reduce the amount of water in dredged sediment and to prepare the sediment for on-site consolidation or upland transport and off-site disposal. Further, the dewatering effluent may need to be treated before it can be disposed of properly or discharged back to receiving water. Several factors must be considered when selecting an appropriate dewatering technology including physical characteristics of the sediment, selected dredging method, and the needed moisture content of the material to allow for the next re-handling, transport, or disposal steps in the process. Two main categories of dewatering that are regularly implemented include gravity dewatering and mechanical dewatering, as described below.

7.5.1.1 Gravity Dewatering

Gravity dewatering is facilitated through natural drainage of sediment porewater to reduce the dredged sediment water content. Gravity dewatering is usually applied to mechanical dredging process options because hydraulic dredging generates very large volumes of water that requires large areas. Gravity dewatering is facilitated through the use of temporary holding barges equipped with weirs or ballasts and filtration systems. Water generated during the dewatering is typically discharged to receiving waters at the construction location directly after settling and filtration. Normal passive dewatering typically requires little or no treatability testing, although characteristics of the sediment such as grain size, plasticity, settling characteristics, and contaminant content are typically considered to determine specific dewatering methods, to determine the size of the dewatering area, and to estimate the timeframe required for implementation. Recent dredging projects (EW T-18 Maintenance Dredging, and the LDW Slip 4 and T-117 Early Action Areas [EAAs]) indicate that project-specific water quality criteria can be met using gravity dewatering through filter media. In addition, project experience and analysis has shown that the contribution of suspended sediments to the water column from dewatering operations are generally less than the contribution from dredging operations. However, additional treatment of dewatering effluent may be considered during remedial design.

Gravity dewatering is generally effective and capable of handling variable process flow rates. Gravity dewatering is fairly simple, but this method can require significant amounts of barge capacity (depending on the volume of material processed and the settling characteristics of the sediment) and time for significant water content reduction.

On-shore gravity dewatering is not anticipated for the EW due to space limitation. Hydraulically dredged sediment dewatering with geotextile tubes[86] has been implemented at several sites to reduce space requirements, but typically still requires significant upland area

[86] A geotextile tube is a fabric enclosure that can be used to contain hydraulic dredge slurry and facilitate dewatering. The fabric is typically a woven geotextile that is selected so that the filtering characteristics of the textile allow discharge of relatively non-turbid effluent from the tube during dewatering. Containment by the tube imposes lateral stress on the dredge slurry, which facilitates more rapid dewatering of the dredge solids than would otherwise occur under passive (gravity) settling conditions.

and project-specific bench-scale evaluations during remedial design to confirm its compatibility with site sediments and to properly select and size the geotextile tubes.

Depending on the desired moisture content of the sediment, the subsequent processing or handling steps, the volume of material to be dewatered, available space, and the ability to effectively manage the dewatering effluent, passive dewatering can be a highly implementable dewatering technology option. Gravity barge dewatering was retained as a representative passive dewatering process option for inclusion in the development of alternatives, primarily because available disposal options can handle wet sediments (see Section 7.3). Other gravity dewatering options should be considered during remedial design.

7.5.1.2 Mechanical Dewatering

Mechanical dewatering involves the use of equipment such as centrifuges, hydrocyclones, belt presses, or plate-and-frame filter presses to separate coarse materials, or squeeze, press, or otherwise draw out water from sediment pore spaces. Mechanical dewatering is typically used in combination with hydraulic dredging to reduce the water content of the dredge slurry prior to beneficial reuse (e.g., sands retained from particle separation methods), ex situ treatment (e.g., thermal), or disposal of the dewatered sediment. A mechanical dewatering treatment train usually includes treating the dewatering effluent prior to discharge.

The mechanical dewatering treatment train typically includes screening to remove materials such as debris, rocks, and coarse gravel. If appropriate, polymers may be added for thickening prior to dewatering. These steps result in a dewatered cake that achieves project-specific volume and weight reduction goals of the dredged sediment. The mechanical dewatering process can be scaled to handle large volumes of sediment, but requires operator attention, consistent flow rates, and consistent sediment feed quality.

Mechanical dewatering is generally an effective technology for both hydraulic and mechanical dredging and has been implemented for a range of sediment types and sediment end uses (e.g., beneficial reuse and upland disposal). It is generally used where achieving moisture content reduction over shorter timeframes is needed. When identified as being needed, mechanical dewatering is evaluated in bench-scale tests during remedial design to develop the specific process design, select equipment, and to select polymer additives if appropriate. Mechanical dewatering costs are included for use with hydraulic dredging technologies; however, additional mechanical dewatering technologies may be considered during remedial design if a need is demonstrated.

7.5.2 Water Treatment

Water treatment refers to a system of tanks, filters, and other equipment used to process water generated during dewatering or transloading activities. Water treatment can be used in concert with either gravity dewatering or mechanical dewatering processes described above. Water treatment systems can be barge-mounted or constructed upland.

The FS assumes water treatment would be required at a transloading facility to manage water generated from dewatering of sediments. Discharge of treated water would likely be directly to the EW or other waterbody. Water treatment technologies in the uplands (e.g., for treatment of stormwater or industrial wastewater) are standard, myriad, and ubiquitous in their application to a wide variety of site-specific conditions. Treatment trains using conventional equipment are capable of treating water generated during sediment remediation projects to levels consistent with ARARs.

Discharge to the King County Metro sewer system could also be considered where the discharge meets flow (i.e., capacity) and chemical parameter limits. This approach would be an off-site disposal action, likely requiring pre-treatment to achieve discharge criteria and comply with all permit requirements (e.g., daily discharge volume), so as not to contribute to an overflow event (e.g., holding tanks for monitored flow).

Water treatment of dredged sediment barge water is assumed to be necessary for diver-assisted hydraulic dredging activities due to the large percentage of water generated compared to dredged sediment. For mechanical dredging, the FS assumes that additional water treatment beyond gravity dewatering (settling and filtration) will not be necessary to meet water quality standards in the construction area.

7.5.3 Best Management Practices

As previously described, short-term water quality impacts and residuals generation can be associated with contaminated sediment removal construction activities. These construction impacts can be mitigated to some degree using operational and barrier control BMPs. This subsection provides a summary review of a wide array of water quality and dredge residual BMPs and discusses the screening of these removal process options for this FS. Additional information regarding effectiveness, implementability, and costs of standard and specialized BMPs employed on environmental dredging projects is provided in Appendix B, Part 5. Standard BMPs are those specified in typical environmental dredging projects, used during dredging, transport, and offloading. The FS cost estimate for dredging assumes that standard BMPs would be employed. Specialized BMPs are sometimes specified during remedial design or triggered during implementation. Specialized BMPs may reduce suspended sediments, but typically reduce production rates, increase costs, and increase design and construction complexity. The FS cost and production rate estimate for dredging assumes that specialized BMPs would not be employed. Post-dredging residuals management contingency actions (RMC, re-dredging) are sometimes considered dredging BMPs, but are discussed in Section 7.2.6.5 and Appendix B, Part 5.

7.5.3.1 Standard BMPs

Operational controls impose limitations on the operation of the equipment being used for removal activities. Dredging BMPs are currently known and established, but may evolve until actual construction. For mechanical dredging, operational control BMPs that reduce re-suspension and loss of contaminated sediments may include the following:

- **Select appropriate dredge equipment:**
  - Conduct intertidal sediment and shoreline bank soil excavation "in the dry" to the degree reasonably possible using land-based equipment.
  - Include an option for an environmental or sealed bucket, where practicable (proper sediment conditions exist).
  - Properly select the dredge bucket for site conditions (i.e., soft sediment versus debris and/or hard digging) to maximize sediment capture and optimize fill efficiency. Adjust methods in changing site conditions.

- **Select dredge methods to increase accuracy and minimize releases:**
  - Perform dredging to the design dredge elevation in a single dredge event, as verified by periodic bathymetric surveys. Using sub-foot accuracy GPS for accurate bucket positioning.
  - Require a debris sweep prior to dredging in known debris areas (debris caught in dredging equipment can cause additional re-suspension and release of contaminated sediments).
  - Minimize the potential for slope failures by maintaining stable side slopes during dredging (e.g., shallow top-to-bottom cuts), including limiting the cut thickness of initial cut depths to avoid sloughing of the cut bank.
  - Start dredging in upslope areas and moving downslope to minimize sloughing.
  - Slow the rate of dredge bucket descent and retrieval (increasing dredge cycle time).
  - Limit operations during relatively high water velocity conditions (turbulence in the vicinity of the dredge bucket during high flow conditions can cause additional re-suspension and release of contaminated sediments).
  - Prevent "sweeping" or leveling by pushing bottom sediments around with dredge equipment to achieve required elevations.
  - Prevent interim stockpiling of dredge material under water.
  - Prevent the overfilling of conventional clamshell (i.e., "open") buckets.
  - Require the slow release of excess bucket water at the water surface.
  - Contain drippage during the overwater swing of a filled bucket (e.g., by placing an empty barge or apron under the swing path during offloading or loading containers directly on barges).
  - Use floating and/or absorbent booms to capture floating debris or oil sheens.
- **Water quality monitoring:**
  - Perform water quality monitoring during dredging to adaptively manage dredging operations and to comply with water quality requirements.
  - Adjust dredging methods (e.g., cycle times) as necessary based on water quality measurements.

- **Control dewatering operations:**
  - Control and reduce the silt burden in runoff from barges using weirs, filtration, and settling.
  - Time water discharges to maximize settlement and filtration efficiency.
  - Prevent overfilling of barges to minimize spillage from barges.
- **Control transload operations:**
  - Use barges that can be made watertight during transit and transloading to allow collection and treatment of generated water.
  - Control and reduce the silt burden in runoff from rehandling areas, using filtration.
  - Use spill plates and spill prevention measures.

Possible additional hydraulic dredging BMPs include the following:

- Changing the method of operating the dredge based on changing site conditions such as tides, waves, currents, and wind.
- Find an optimal rate and method of operation for a given set of conditions. Sediment resuspension is generally minimized at the same point that production is optimized.

7.5.3.2 Specialized BMPs

Engineered barrier controls at environmental dredging and capping sites typically include two different technologies (USACE 2008a):

- Silt curtains and silt screens
- Rigid containment (e.g., sheetpiles or cofferdams)

Each of these engineered barrier controls are discussed below.

Silt Curtains and Screens

Silt curtains and screens are specialized BMPs that have proven effective in reducing surface water turbidity in relatively quiescent environments and are a common BMP used to retain suspended sediment plumes at environmental dredging sites located in low-energy environments without deep water (Francingues and Palermo 2005). Water passes below or around fabric curtains because they are not typically sealed with the bottom. Water also discharges around the curtains when they are opened to allow the necessary passage of work equipment. As discussed in Bridges et al. (2010), based on a review of the available data, there is uncertainty as to whether silt curtains are effective in retaining contaminants within the curtain footprint, and there are also concerns that contaminants can migrate below the bottom of the curtain while the curtain is in place or upon curtain removal.

An evaluation of the effectiveness of silt curtains for environmental dredging was recently performed by Alcoa (under EPA oversight) within a relatively low-energy environment of the Lower Grasse River (Connolly et al. 2007). Water quality monitoring performed both inside and outside of the silt curtains revealed that the curtains had little effect in controlling downstream dredging-related releases of dissolved PCB concentrations, which made up roughly 69% to 89% of the total PCBs. Silt curtains achieved localized reductions in TSS concentrations, but did not appear to be necessary to achieve TSS-based water quality criteria (Alcoa 2006). Moreover, concentrated flow conditions beneath the silt curtains resulted in localized scour and re-suspension, which periodically increased downstream contaminant transport. These conditions limit the ability of the curtain to effectively contain dredging-related contaminant releases to the work area (EPA 2005).

Implementability concerns have also been documented on several projects, including the Lower Grasse River (Connolly et al. 2007), the San Jacinto River (Anchor QEA 2011), and other environmental dredging projects that deployed silt curtains (EPA 2005). For example, short-term pressure waves and flow increases in the Lower Grasse River routinely damaged the silt curtains. These issues are exacerbated in deeper water, which requires a deeper curtain that can act as a bigger "sail" and can also be difficult to effectively anchor. The displaced curtains can also become a hazard to navigation and/or block access to the work area, and the curtains often need to be frequently repositioned or re-anchored. Generally, the use of silt curtains and screens have significantly reduced overall dredge production rates (e.g., see Connolly et al. [2007]), and typically lead to significantly extended schedules to complete remediation, consequently increasing the impact from the dredging operation. For these reasons, and because the deep water depths in the EW would preclude the use of full curtains, silt curtains are not retained as a BMP.

Rigid Containment

As discussed in Bridges et al. (2010), rigid containment barriers (e.g., sheetpiles or cofferdams) are occasionally used to contain re-suspension during environmental dredging operations, particularly in high-energy environments, although with different technological limitations. The EW is not a high-energy environment and has technical limitations related to the implementation of a standard sheetpile wall as rigid containment. The maximum practical depth of water for sheetpiles in the EW is approximately 35 to 40 feet. Beyond that depth, the sheets cannot be embedded sufficiently to resist the lateral forces imposed by the water pressure. In areas deeper than 35 to 40 feet, a cellular cofferdam would need to be constructed for rigid containment. Cellular cofferdams have considerable implementability issues including the time required for construction and the hazard to navigation they would create once in place. Because of the construction duration, it is not practical to construct and remove a cellular cofferdam structure to accommodate seasonal work windows.

While several case studies have demonstrated reductions of dredging-related releases outside of the sheetpile-enclosed area (relative to releases that would have occurred without containment), release of contaminants beyond the barrier still occurs, as in practice it has not been possible to place a watertight barrier. For example, during the Hudson River Phase 1 environmental dredging project, roughly 1% of the mass of PCBs dredged within sheetpile enclosure areas was released through the barrier, largely due to leakage through ports at the interlocks (Anchor QEA and Arcadis 2010).

Removal of rigid barriers can also have unintended and undesirable consequences. Adhered sediment can be re-suspended into the water column during pile pulling, resulting in re-suspension of deeply buried contaminants. Recontamination of adjacent sediment cap areas occurred during removal of a wall at Colman Dock in Seattle, due to mobilization and release of deeply buried PAHs in the area (Ecology 1995). Furthermore, suspended- or dissolved-phase contaminants may still be present in the water column at the time that the sheetpile are removed, resulting in release of contamination. Another limitation to rigid containment is the reduction in waterway width during placement, thereby reducing the cross section area for flow and increasing flow velocities and scour potential.

The use of rigid containment is not expected in the EW, and not retained for the remedial alternatives.

7.6 General Site Conditions Affecting Remedial Technology Selection

The preceding sections described the site-wide screening and application of remedial technologies. Table 7-2 provides a summary of considerations for applying remedial technologies within the EW OU. The purpose of the table is to provide a single summary of the framework used for the CMA-specific evaluation of remedial technologies in subsequent sections. Additional information on specific constraints associated with each CMA is provided in Section 7.7. Section 7.8 describes the applicability of individual technologies within each CMA.

7.7 Construction Management Areas

The EW OU is an industrial waterway with structures (e.g., pile-supported piers, bridges, and riprap slopes) located in nearly all shoreline areas. Sediments with COCs above RALs are located under and adjacent to these structures in many areas of the EW OU, which restricts the technical and economic feasibility of implementing specific technologies and process options. Specific factors that may restrict the implementability include site access (e.g., feasibility of staging from upland facilities, homeland security issues within Pier 36); physical obstructions and structural conditions such as piers, bridge structures, or partially demolished aquatic structures; water depths (i.e., site bathymetric conditions); and navigation and other site use considerations. Based on these factors, the EW has been divided into specific CMAs that represent areas with similar structural conditions, or similar aquatic use, habitat, or water depth conditions.[87] These CMAs are shown on Figure 7-1 and defined in Table 7-3.

Structural restrictions and use, habitat, and water depth considerations associated with various areas of the EW are described in Sections 7.7.1 and 7.7.2, respectively, and shown on Figure 7-1. Figures 2-9 and 2-10 show typical underpier cross sections for T-18 and T-25/T-30, respectively, which identify key structural elements described in Section 7.7.1.

[87] The CMAs were slightly modified since the Screening Memo (Anchor QEA 2012) by further subdividing CMAs into smaller areas for the purpose of evaluating applicable remedial technologies.

Table 7-2

Summary of General Site Conditions Affecting Remedial Technology Selection

Technology	Elevation Requirements and Restrictions[a]	Sediment Stability	Implementability
Removal	**Navigation channel and berthing areas:** No restrictions on vertical extent of removal, except as limited by practicability (e.g., adjacent structures). **Habitat areas (depths shallower than -10 feet mean lower low water):** Assume backfill to existing grade following removal to maintain habitat. Surficial material will consist of suitable habitat substrate.	Slope transitions will be designed with appropriate side-slopes (e.g., 3 horizontal to 1 vertical [3H:1V] or shallower).	Full removal is defined as removal to the extent practicable in all areas. The FS assumes that no structures will be removed, which is not practicable in all locations. In underpier areas, under bridges, near engineered shorelines (e.g., piers, riprap, bulkheads, and slopes), and near utilities, removal will be limited by structural considerations and offsets will be considered adjacent to structures.
Partial Dredging and Capping	**Navigation channel and berthing areas:** Partial dredging is assumed to be completed so that the top of the cap has an appropriate clearance below the authorized navigation depth in the navigation channel to account for overdredge and the vertical accuracy of dredging equipment. Figure 7-2 displays the current authorized dredge depths by area. **Habitat areas:** Partially dredge to the thickness of the cap, and cap to grade. Finish with habitat-suitable substrate.	Capping is engineered with appropriate stone size for scour mitigation; cap thickness considering contaminant transport, scour, and consolidation; and slopes for geotechnical stability. For the FS, a cap thickness of 5 feet is assumed, with slope transitions typically designed at 3H:1V or shallower, and the potential need to design and construct steeper slopes in limited locations due to site restrictions. The toe of slopes for areas adjacent to the navigation channel are assumed to have appropriate horizontal and vertical clearance to account for future maintenance dredging activities.	Partial dredging is limited by structural considerations, as described for removal above. Capping is limited by structural considerations, such as the impact of material on piles and settling of underlying sediment.
Enhanced Natural Recovery (ENR)	**Navigation and berthing areas:** Partial dredging is assumed to be completed in areas shallower than the authorized (channel) and maintained (berth areas) navigation depth so that the top of the ENR has an appropriate clearance below the authorized navigation channel depth to account for overdredge and the vertical accuracy of dredging equipment. **Habitat areas:** ENR is not restricted based on habitat.	ENR is generally applicable in locations with limited scour potential; however, mixing is an aspect of ENR. The grain size or thickness of ENR material can be adjusted to improve the stability characteristics of the ENR layer.	ENR is applicable in some areas with access limitations (i.e., under the low bridge areas) because other remedial technologies are not constructible. ENR is not applicable to some underpier areas (T-18, T-25, Slip 27, T-30, and T-46) due to instability on steep slopes.
In situ Treatment	**Navigation and berthing areas:** In situ treatment is not assigned in navigation or berthing areas because other implementable and effective technologies are available in these locations. **Habitat area:** In situ treatment is not restricted based on habitat.	The in situ treatment layer is expected to mix with underlying sediment. The grain size of in situ material could be adjusted to improve the stability characteristics of the in situ treatment layer.	In situ treatment is anticipated to be applicable in areas with practicability concerns (i.e., underpier areas), due to the particle sizes, and minimal thickness of material being placed. In situ treatment is more constructable than capping or ENR in underpier areas.
Monitored Natural Recovery (MNR)	No elevation requirements or restrictions.	MNR is generally applicable in locations with higher sedimentation rates and less scour. MNR effectiveness may be improved when combined with remediation of adjacent areas (e.g., underpier areas adjacent to removal with residuals management cover areas).	MNR is suitable for difficult-to-access areas because of the inability to meet remedial action objectives with other remedial technologies, particularly when combined with remediation of adjacent areas.
Institutional Controls	Will be applied to all areas of the East Waterway Operable Unit.	Not affected by stability.	Can be implemented at the site, although has effectiveness concerns.

Note:

a. As discussed in Section 2.9.2, USACE completed a draft Seattle Harbor Navigation Improvement Project Feasibility Report and Environmental Assessment in August 2016, which includes alternatives for deepening and widening the federal navigation channel. Because the implementation of the navigation improvement project is uncertain, the assumptions for remedial technologies (e.g., post-capping elevation requirements) are based on current conditions and uses. However, all EW remedial technologies are also compatible with the future implementation of the potential navigation improvement project, and the navigation improvement would not reduce the environmental protectiveness of the remedy in the EW.

FS – Feasibility Study T – terminal USACE – U.S. Army Corp of Engineers

Table 7-3
Construction Management Areas in the East Waterway

Construction Management Area	Description	Structural Restrictions	Use, Habitat, and Water Depth Considerations
Junction Reach	Located south of the Spokane Street corridor and north of the junction with the LDW. Both west and east sides of the EW in this area contain riprap slopes, with floats for small vessels along the west side of the waterway.	Piles and small vessel floats are present in the waterway, but present minimal structural restrictions in this area. It is assumed that dredging adjacent to the piles should be minimized, and dredging at the base of slopes should consider overall slope stability. Existing riprap slopes may limit the ability to conduct remediation immediately adjacent to the riprap slopes without slope improvements.	A shallow bench along the eastern shoreline at T-104 was constructed of fine-grained substrate and provides valuable shallow water habitat for juvenile migratory fish, and intertidal areas provide clam habitat. Small draft recreational and commercial boats move in and out of the Harbor Island Marina (T-102) from the LDW. Tribal netfishing may occur within this area.
Sill Reach	Located under the bridges in the Spokane Street corridor. Four bridge structures pass through this area, including the Spokane Street Bridge and Service Road Bridge between T-102 and T-104, West Seattle Bridge, and BNSF Railway (Railroad Bridge). Elevations in this area range from -4 to -11 feet MLLW.	The West Seattle bridge columns located in the water on each side of the EW are supported by a pile-supported footing or pile cap (approximately 26 feet by 32 feet each) with top of footing at approximately -7 feet MLLW. There are similar-sized pile caps for columns upland on each side of EW. Additional areas adjacent to these columns may have seen some soil improvements that provide additional structural stability to the column and should be considered if significant soil were to be removed. The existing bridge structures limit access for equipment and may restrict removal and/or containment remedial actions underneath the bridges, or immediately adjacent to the bridge structures. The bridge structures are considered critical infrastructure to transportation needs.	Clam habitat is present in intertidal areas. Habitat restoration is proposed for the west side of the EW under the West Seattle Bridge, which would provide off-channel mudflat and marsh habitat, along with riparian vegetation. The project would also involve removal of debris and creosote structures from the shoreline areas. The restoration is subject to Natural Resource Damage Trustee approval, EPA coordination, and obtaining permitting from federal, state, and City agencies. No timeline is established for construction.
Shallow Main Body – South	Located north of the Sill Reach before the EW widens to its full 750 feet width. This area is used to moor tugs and barges along the western side, where a concrete bulkhead is present. There is also a wooden wharf pile-supported structure in-line and to the south of the concrete bulkhead. Details on the date and type of original construction of these structures are unknown. This CMA is within the portion of the federal navigation channel authorized to -34 feet MLLW.	Design and construction details of the concrete bulkhead and timber wharf structure on the west side of the EW are unknown. The condition of the concrete structure is relatively poor, however, based on visual observation. Dredging adjacent to the bulkhead may cause structural impacts.	Numerous barges and tugboats are moored along the west side of the CMA. This CMA also contains a mound of rock placed in the southeast portion of this area specifically for habitat restoration purposes. The mound provides shallow water habitat just north of the Spokane Street pedestrian bridge. Tribal netfishing occurs within this area. Shoreline slope stabilization has recently been proposed along the northwest corner of this CMA (independent of CERCLA).
Former Pier 24 Piling Field	A timber bulkhead and timber piles are present along the southern shoreline of Pier 24. The top of the existing bulkhead is lower than high tides. Removal is planned for these piles, a small pier, and in-water debris, which occupy approximately 2.1 acres of aquatic and shoreline area for fish and wildlife habitat improvements. No timetable for this work is currently established based on the need to coordinate with CERCLA actions. This work may be completed in conjunction with the CERCLA action or may be conducted for habitat restoration purposes ahead of the CERCLA action.	Removal or cutting of piles would be required prior to implementation of remedial alternatives in this area. Structural condition of the existing bulkhead wall is severely deteriorated. As such, removal of the piles and/or any dredging in this area will require strengthening of this wall or removal of the wall plus associated upland grading to contour in-water and upland slope to final desired grades.	This area is potentially slated for Port habitat restoration.
Shallow Main Body – North	Located north of where the EW widens to its full 750 feet and south of the navigation area maintained at -51 feet MLLW. This area extends approximately from Station 4950 to Station 6200 and is included in the portion of the federal navigation channel authorized to -34 feet MLLW.	No structural restrictions.	The water depths in this area reach a maximum depth of -45 feet MLLW (except for the berthing area at T-25, which was designed for -50 feet MLLW). Some limited vessel navigation occurs in this area, including container ships to T-25 at high tide. Tribal netfishing occurs within this area.

Table 7-3
Construction Management Areas in the East Waterway

Construction Management Area	Description	Structural Restrictions	Use, Habitat, and Water Depth Considerations
Underpier Areas	Underpier areas apply to T-18, T-25, Slip 27, T-30, Pier 36/37, and T-46 and extend from approximately 125 feet shoreward of the Pier Head Line.	Due to very limited access to underpier areas, only from the water, it is considered extremely difficult to remove sediments from the underpier slopes. Specialized dredging equipment may be capable of removing some of the underpier sediment, but not 100% of sediment. Any underpier removal work would likely need to be conducted using diver assisted methods, and the risks for injury and death during construction will need to be weighed against long-term risk of leaving contaminated sediment in underpier areas. Capping or placement of certain ENR materials within the underpier areas may be infeasible due to equipment access and placement issues. Also, the underpier slopes are typically too steep to place a stable cap over them, and a potential drawdown effect on piling from placing material on the slopes may cause structural damage.	Underpier areas provide habitat for rockfish and epibenthic food for salmon. However, in situ treatment in underpier areas is not restricted based on habitat.
Berth Areas (T-18, T-25, T-30)	Berth areas extend along T-18, T-25, and T-30 and are approximately 150 feet wide. Berth areas at T-18 and T-25 extend from the pier head line into the federal navigation channel.	Berth areas within the EW are actively used by a variety of vessels, the largest of which are container ships. Required berthing elevations typically match the federal navigation channel's authorized elevation of -51 feet MLLW. Removal in front of these terminals may need to limit dredging depths and may include setback areas from the structures to avoid adversely impacting the existing pile-supported wharves. At T-18, a sheetpile wall was installed to provide slope stability to allow dredging along the toe of slope between approximate Stations 4950 and 1900 (terminating at Communication Cable Crossing at bent 213). The capacity of the existing sheetpile wall limits any significant additional material removal at the toe of slope; the sheetpile was designed for a dredge elevation of -51 feet MLLW. The keyways at the base of riprap slopes at T-25 and T-30 are at approximately -50 feet MLLW. For T-18 south of Station 4950, no sheetpile wall exists; T-25 has not had any significant structural berth deepening performed since initial construction in the 1970s. As such, it is unlikely that the structure can accommodate dredging below the initial design dredge elevation. Recent improvements at T-30 (accomplished by the Port in 2007) were completed to allow for dredging in the berth area to -50 feet MLLW.	Along T-18, berthing area elevations are -51 feet MLLW from Station 0 to 4950. Berth 6 (south of Station 4950) depths at T-18 are approximately -35 to -40 feet MLLW. Along T-25, berthing area elevations are -50 feet MLLW. Along T-30, berthing area elevations are -50 feet MLLW. Tribal netfishing occurs within these areas.
Slip 27 Channel/ Pier 28	Slip 27 is located on the east side of the EW, between T-25 and T-30. It is 850 feet long and 240 feet wide. Pier 28 is the concrete structure located on the north side of Slip 27.	A 34-foot-wide truck bridge is present in the eastern portion of Slip 27 connecting T-25 and T-30. This bridge is located to the west of a structural bulkhead wall. The wall and bridge will likely limit the maximum depth of dredging in this area. Pier 28 is a concrete deck and concrete pile structure that is considered at or near the end of its useful life. Structural observations of this facility in 2001 indicate that the pier is deteriorated.	Miscellaneous vessels berth in Slip 27. Pier 28, at the northern portion of the slip, is currently used to berth various vessels and barges. The Slip 27 and Pier 28 areas provide shallow water habitat for juvenile migratory fish, and intertidal areas provide clam habitat. Tribal netfishing occurs within this area.
Slip 36/ T-46 Offshore	Slip 36 is located on the east side of the EW, between Pier 36 and Pier 37. It is approximately 1,200 feet long and 300 feet wide.	Recent construction work on Pier 36 and within Slip 36 included dredging the berth areas to -40 feet MLLW. Further sediment removal may be limited without structural impacts. Recent dredge work at Terminal 46 determined that a non-structural maintenance dredge was possible to allow a berth depth of -51 feet MLLW. Further deepening of the berth area along the west face of the Pier 46 apron would likely require associated structural improvements.	USCG vessels frequent Slip 36, which serves Pier 36 (south) and Pier 37 (north). The western half was dredged to -40 feet MLLW in 2005. USCG berths numerous vessels in Slip 36, and has homeland security access restrictions.

Table 7-3
Construction Management Areas in the East Waterway

Construction Management Area	Description	Structural Restrictions	Use, Habitat, and Water Depth Considerations
Mound Area/ Slip 27 Shoreline	This area is located on the east side of the EW just south of the mouth of Slip 27 and along the southern and eastern shoreline of Slip 27. It is open slope, typically with a riprap face.	Possible that structural walls could be necessary to accomplish significant removal of material along this slope without impacting the slope and/or yard area above.	The upland areas along the southern part of Slip 27 have been replanted as part of habitat restoration. The restoration extends from the top of bank (18.5 feet MLLW) down to 12 feet MLLW. The shallow water and intertidal areas also provide habitat for clams and juvenile salmon. Tribal netfishing occurs within this area.
T-25 Nearshore	This area is located on the east side of the EW, between the T-25 Pier and the Mound Area. It is open slope, typically with a riprap face.	Possible that structural walls could be necessary to accomplish significant removal of material along this slope without impacting the slope and/or yard area above.	The shallow water and intertidal areas also provide habitat for clams and juvenile salmon. Tribal netfishing occurs within this area.
T-30/Coast Guard Nearshore	This area is located on the east side of the EW, between Slip 27 and Slip 36.	This area includes several deteriorated structures including remnant piers and both sheetpile and rock bulkhead walls. The specific structural condition of all structures is unknown but appears to be severely deteriorated, suggesting that additional dredging and slope modifications would be problematic without associated structural improvements. This FS assumes that the derelict structures may be removed to facilitate remediation as needed.	Jack Perry Park is a 1.1-acre park located north of T-30 and south of the USCG facility. It provides 120 feet of intertidal area and shoreline access for public recreational activities. Smaller vessels, such as tugboats, barges, and Tribal fishing vessels navigate in this nearshore area. Future development along the shoreline of T-30 is possible, which could result in water depth requirements of -50 feet MLLW (the same as the current T-30 berth area water depth requirements). Shoreline areas provide shallow water habitat for juvenile migratory fish, and intertidal areas provide clam habitat. Tribal netfishing occurs within this area.
Communication Cable Crossing	A communications cable crosses the EW between T-18 and the northern portion of T-30 (Figure 7-1). This cable was originally buried between -61 and -66 feet MLLW in 1972 in an armored trench. The location shown on Figure 7-1 changed following repair due to a vessel anchor incident at T-18. During the T-18 North Apron Upgrade in 2006, the existing crossing at the T-18 face of bullrail was located between bents 213 and 214 (Station 1850). On the T-30 side, the approximate crossing location is indicated by a visible marker on the shore (Station 1550).	For the purposes of this FS, it is assumed that the depth of sediment removal may be limited in this area by the presence of the cable crossing.	Water depths in the footprint of the cable crossing range from -53 feet MLLW to -59 feet MLLW in the federal channel and berth areas. Vessel use is similar to the navigation channel, T-18, and T-30. Tribal netfishing occurs within this area.
Deep Main Body – North	The Deep Main Body – North is 450 feet wide and extends from Station 0 to between Stations 2970 and 3590, depending on location (boundary varies from east to west as shown on Figure 7-2). The channel is authorized to -51 feet MLLW, and maintained to -51 feet MLLW.	No structural restrictions.	The authorized channel elevation of -51 feet MLLW is required to support movement of large container ships throughout the EW. Most vessel traffic consists of shipping companies moving container ships and assorted tugboats into and out of the EW. Each container ship requires at least one tugboat to maneuver the ship during docking and undocking. Container ships call at T-18, T-25, and T-30. Other vessels, such as tugboats, barges, and USCG vessels, regularly use the navigation channel. Also note the Communication Cable Crossing described earlier in this table. Tribal netfishing occurs within this area.

Table 7-3
Construction Management Areas in the East Waterway

Construction Management Area	Description	Structural Restrictions	Use, Habitat, and Water Depth Considerations
Deep Main Body – South	The Deep Main Body – South is 450 feet wide and extends from Station 4950 to between Stations 2970 and 3590, depending on location (boundary varies from east to west as shown on Figure 7-2). It is within the federal navigation channel and is authorized to -34 feet MLLW but is maintained to -51 feet MLLW.	No structural restrictions.	Maintenance of this portion of the authorized channel to -51 feet MLLW is required to support movement of large container vessels into berthing areas at T-18 and T-25. Most vessel traffic consists of shipping companies moving container ships and assorted tugboats into and out of the EW. Each container ship requires at least one tugboat to maneuver the ship during docking and undocking. Container ships call at T-18 and T-25. Other vessels, such as tugboats, barges, and USCG vessels, regularly use this area. Tribal netfishing occurs within this area.

Notes:
BNSF – BNSF Railway
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CMA – Construction Management Area
ENR – enhanced natural recovery
EPA – U.S. Environmental Protection Agency
EW – East Waterway
FS – Feasibility Study
LDW – Lower Duwamish Waterway
MLLW – mean lower low water
Port – Port of Seattle
USCG – U.S. Coast Guard
T – Terminal

7.7.1 Structural Restrictions

A number of structural restrictions present in the EW may preclude the use of specific remedial technologies due to limited site access or potential for adverse impacts to structural or slope stability. The proximity to these structures may limit the ability to implement certain remedial technologies or process options. Detailed information on adjacent facilities and infrastructure is found in the EISR (Anchor and Windward 2008a). A summary of these structural restrictions and the assumptions developed in the absence of detailed structural information are provided in Table 7-3. Figures 2-9 and 2-10 show detailed structural information that is available for T-18, T-25, and T-30.

7.7.2 Use, Habitat, and Water Depth Considerations

Use, habitat, and water depth considerations in the EW could potentially limit the range of remedial technologies that could be considered for specific CMAs. The navigation channel and berthing areas have minimum water depths required for vessel operations. Navigation for container ships and other smaller vessels is a current and anticipated future use of the EW navigation channel and adjacent berths. Therefore, maintenance dredging depth requirements must be considered for remediation. In addition, as described in Section 2.9.2, USACE completed a draft SHNIP Feasibility Report and Environmental Assessment in August 2016, which includes alternatives for deepening and widening the federal navigation channel. Because the implementation of the navigation improvement project is uncertain, the assumptions for the EW FS alternatives are based on current conditions and uses but are compatible with the future implementation of the potential deepening of the navigation channel, and the navigation improvement would not reduce the environmental protectiveness of the remedy in the EW.

Intertidal and nearshore habitats may be home to diverse communities of fish, birds, and invertebrate species. Therefore, areas with depths shallower than -10 feet MLLW will be managed in ways that approximately restore pre-construction elevations. These considerations are detailed in Table 7-3 and shown on Figure 7-1.

7.8 Summary of Representative Process Options for the Feasibility Study

A summary of the screening of remedial and disposal technologies for the EW OU is provided in Table 7-4. This table combines the information in the preceding sections to provide a CMA-specific screening of remedial technologies. For the purpose of assigning remedial technologies, the CMAs are grouped into eight areas based on similarity of physical features and potential remedial actions. The following sections discuss the eight groups of CMAs and the applicable remedial technologies retained or eliminated for each. This screening was based on the Screening Memo (Anchor QEA 2012a); however, modifications were made based on further analysis of the site. Some technologies were eliminated based on additional considerations, resulting in fewer remedial technologies retained for individual CMAs in the FS than in the Screening Memo. As discussed previously in this section and in the Screening Memo, the applicability of the remedial technologies could be revisited during remedial design, as conditions dictate.

7.8.1 Deep Main Body and Berth Areas

The Deep Main Body and Berth Areas include eight CMAs:

1. Deep Main Body – North
2. Deep Main Body – South
3. T-18 Berth Area
4. T-30 Berth Area
5. T-25 Berth Area
6. Slip 27 Channel
7. Slip 36 Channel
8. T-46 Offshore

These CMAs are characterized by elevation constraints from maintenance dredging and potential for vessel propwash scour from maneuvering vessels. Maintenance dredging elevations range from -51 to -35 feet MLLW.[88] Removal, capping (with partial dredging), and ENR (with partial dredging) were retained for these areas; MNR and in situ treatment were eliminated.

[88] As discussed in Section 2.9.2, the maintenance dredging elevations could be modified in the future if the SHNIP is funded and implemented. Retained technologies are compatible with potential EW navigation channel deepening.

Table 7-4

Applicability of Retained Remedial Technologies to East Waterway Construction Management Areas[a]

Construction Management Areas (CMAs)	No Action	Natural Recovery		In situ Treatment	In situ Containment	Removal
		Monitored Natural Recovery (MNR)	Enhanced Natural Recovery (ENR)	Amendments	Capping or Partial Dredging and Capping	Dredging or Dry Excavation
Deep Main Body, Shallow Main Body, and Berth Areas – Deep Main Body, Deep Draft Berth Areas (T-18, T-30, T-25), Slip 27 Channel, and Slip 36/T-46 Offshore	**Retained**	**Eliminated**	**Retained**	**Eliminated**	**Retained**[b]	**Retained**
Underpier Areas	**Retained**	**Retained**	**Retained** for Slip 36 underpier areas **Eliminated** for all other underpier areas (T-18, T-25, Slip 27, T-30, and T-46)[c]	**Retained**	**Retained** for Slip 36 underpier areas **Eliminated** for all other underpier areas (T-18, T-25, Slip 27, T-30, and T-46)[c]	**Retained**[d]
Shallow Main Body Reach	**Retained**	**Eliminated**	**Retained**[e]	**Eliminated**	**Retained**	**Retained**
Sill Reach – West Seattle Bridge and low bridges (Railroad Bridge and Spokane Street Bridge)	**Retained**	**Retained** for the low bridge areas (Railroad Bridge and Spokane Street Bridge) **Eliminated** for the West Seattle Bridge area	**Retained**	**Retained**[f]	**Eliminated**	**Retained** for the West Seattle Bridge area **Eliminated** for the low bridge areas (Railroad Bridge and Spokane Street Bridge)
Junction Reach	**Retained**	**Retained**[g]	**Retained**[g]	**Retained**[g]	**Retained**[g]	**Retained**
Former Pier 24 Piling Field	**Retained**	**Eliminated**	**Retained**[h]	**Eliminated**	**Retained**	**Retained**
Nearshore Areas (not used as Berths) – Mound Area/Slip 27 Shoreline, Coast Guard Nearshore, T-25 Nearshore, and T-30 Nearshore	**Retained**	**Eliminated**	**Eliminated**	**Eliminated**	**Retained** for Mound Area/Slip 27 Shoreline and Coast Guard Nearshore **Eliminated** for T-25 Nearshore and T-30 Nearshore	**Retained** for T-25 Nearshore and T-30 Nearshore **Eliminated** for Mound Area/Slip 27 Shoreline and Coast Guard Nearshore
Communication Cable Crossing	**Retained**	**Eliminated**	**Retained**	**Eliminated**	**Eliminated**	**Retained**

Notes:

a. The technology screening is only for FS purposes; all technologies may be considered during remedial design.
b. Although capping is retained for these CMAs, no alternative incorporates capping because the partial dredging depth needed to gain clearance for the cap is deeper than the contamination thickness in most locations. Therefore, most contamination would be removed by partial dredging, making capping unnecessary.
c. Slopes in T-18, T-25, Slip 27, T-30, and T-46 underpier areas are too steep for ENR or capping placement.
d. Diver-assisted hydraulic dredging was retained for underpier areas since removal using mechanical dredging equipment is not feasible in these areas.
e. Although partial removal and ENR was retained in the Shallow Main Body Reach, there is no alternative that incorporates this technology for this CMA because only small areas of the Shallow Main Body Reach were applicable for ENR-nav, and broader areas were applicable for partial removal and capping. Therefore, partial removal and capping was retained for the alternatives.
f. In situ treatment was retained in the Sill Reach; however, in situ treatment was not incorporated in the alternatives in the Sill Reach because other more common and effective remedial technologies are available. In particular, coarser-grained and more dense sand and gravel that would be specified for ENR are likely to be stable and effective in the location.
g. Although MNR, ENR, in situ treatment, and capping were retained for this in the Junction Reach, there are no alternatives that incorporate these technologies in this CMA because the alternatives that include remediation of the Junction Reach focus on removal.
h. Although ENR is retained for the Former Pier 24 Piling Field for consideration during design, ENR is not incorporated into the remedial alternatives for this CMA because of the only small areas were applicable for ENR-nav, and broader areas were applicable for partial removal and capping, therefore partial removal and capping was retained for the alternatives.

Institutional controls are part of all alternatives.
FS – Feasibility Study
T – terminal

Removal was retained for these CMAs for the reasons summarized in Section 7.2.6.6. As discussed in that section, shoreline structures such as piers will limit full removal in some locations. Shoreline structures are assumed to remain intact during remediation, and contamination left behind due to structural considerations will be addressed as part of residuals management following removal activities.

Capping was retained in conjunction with partial removal to gain clearance for future maintenance and navigation activities described in Section 7.2.5.3. Although partial removal and capping was retained in this screening, there is no alternative that incorporates this technology because the thickness of contamination is less than the required partial dredging depth in most locations. Therefore, most contamination would be removed by partial dredging, making capping unnecessary.

ENR was retained in conjunction with partial removal as necessary to gain clearance for maintenance and navigation activities (i.e., so the top of the placement layer is below the authorized or maintained navigation depth). ENR was incorporated into the remedial alternatives as ENR-nav, which would include additional measures to accelerate natural recovery and to mitigate the impact of vessel scour on surface sediment chemistry in the biologically active zone in areas that potentially have deep sediment mixing. For the FS, this is assumed to be a thicker layer of ENR with an average thickness of 18 inches (in order to achieve a minimum of 15 inches), which is roughly double the typical ENR application of 9 inches in other ENR areas). The thicker layer would mitigate the impact of scour by increasing the scour depth necessary to impact underlying sediment and increase the mass of clean sediment to mix with underlying sediment. In addition, this FS assumes that ENR-nav would only be employed in areas with relatively low sediment concentrations (e.g., between RALs and 2x RALs) to further reduce the impact of potential mixing of ENR-nav material with underlying sediment.

MNR was eliminated due to potential for resuspension of surface and subsurface contaminated sediment from erosive forces from propeller wash, and because future maintenance dredging could remove newly deposited sediment. In situ treatment was eliminated because other more common and effective remedial technologies are available. In particular, in situ treatment has not been used in areas with prop-scour forces similar to the

EW, and there are concerns that AC, which has a lower density than native sediments, may not be stable over the long term in areas where resuspension can occur.

7.8.2 Underpier Areas

The EW contains aprons, docks, and overwater structures (generalized here by the term piers) along the east and west shorelines. Piers over water represent approximately 14 acres of sediment of the EW OU. Piers present special challenges for addressing contaminated sediment residing underneath and adjacent to these structures. In general, the underpier areas are characterized by the following:

- Access limited by piers and piles
- Pile stability considerations and other structural considerations
- Steep slopes (stabilized with riprap, bulkhead, or sheetpile)
- Close proximity to SDs and CSOs
- Potentially high-energy environment due to maneuvering vessels

Only three technologies are considered suitable for meeting the technical challenges of remediating underpier areas: MNR, in situ treatment, and removal to the maximum extent practicable. ENR and capping are not included in the EW FS alternatives because of the small area where these technologies are applicable. However, ENR and capping may be considered during remedial design for underpier areas with slopes less than 1.75H:1V (e.g., Slip 36).

Although the underpier areas are a relatively high-energy environment, MNR was retained for underpier areas for several reasons. First, most other remediation technologies will be challenging to implement under piers; therefore, MNR is significantly more practicable than other forms of remediation. Second, underpier areas have high recovery potential following the remediation of adjacent open-water areas because of sediment exchange between these areas (the sediment exchange may also result in higher concentration sediments being deposited in open-water areas, as demonstrated by modeling results). Third, underpier areas have relatively small spatial extent and, therefore, are expected to contribute less to site-wide risks from bioaccumulative compounds, as shown in model predictions (e.g., see Appendix J sensitivity runs for Alternative 1A(12)).

In situ treatment was retained because it is anticipated to reduce bioavailability of contaminants with relatively small amounts of placed material. The thin layer of material is more likely to stay in place on steep slopes than a thicker ENR layer and has fewer constructability challenges than construction of a stable cap over a steep riprap slope. Potential methods for placing in situ treatment materials under the piers are discussed in Section 7.2.7.1.

Standard removal using mechanical dredging equipment is not feasible when working in underpier areas; therefore, diver-assisted hydraulic dredging was retained for underpier areas. Dredging in underpier areas has the most practicability and construction (i.e., diver) health and safety concerns compared to other remedial technologies. This FS assumes that a contractor would conduct diver-assisted hydraulic dredging by working around and underneath the existing pier structures to remove as much of the contaminated sediment as practicable above the slope riprap layer.

Because of technical challenges, complete removal of all contaminated sediment not being possible, diver health and safety concerns, and high cost of dredging the underpier areas, limited removal was retained to remove sediment with the highest concentration (e.g., hot spot areas). A dredging-specific action level was developed for FS costing purposes to address areas with the highest contaminant concentrations under the piers. For select alternatives, underpier sediment with concentrations above CSL for PCBs and mercury (65 mg/kg OC and 0.59 mg/kg dw, respectively) would be dredged. In situ treatment would be applied to the rest of areas with surface sediments exceeding RALs, as described above. These thresholds were developed based on the expectation that areas remaining above RALs but below these higher thresholds will be reduced to acceptable levels through in situ treatment.

In addition to limited removal in underpier areas, removal to the maximum extent practicable was also retained for select remedial alternatives to compare the costs and benefits of extensive hydraulic dredging under the piers.

Capping, partial dredging and capping, and ENR were not retained for some underpier areas (T-18, T-25, Slip 27, T-30, Pier 36/37, and T-46) due to the inability of placing and stabilizing a thick layer of material on steep slopes and around piles. These technologies may be considered during remedial design in less steep underpier areas (e.g., Slip 36), where they may be feasible.

7.8.3 Shallow Main Body Reach

At the southern extent of the federal navigation channel, the maintained navigation elevation changes from a maximum elevation of -51 feet MLLW to -34 feet MLLW. As shown in Figure 7-1, this area is split into the two Shallow Main Body Reach CMAs, the North, from Stations 4950 to 6200, and the South, from Stations 6200 to 6850. Although the authorized navigation elevation is -34 feet MLLW, the Shallow Main Body – North CMA has deeper water depths and some maintained berth areas (maximum elevation of -45 feet MLLW). The existing elevations in the Shallow Main Body – South CMA vary significantly (e.g., changes from an elevation of -40 feet MLLW at Station 6200 to -10 feet MLLW at Station 6850). Dredging, capping (with partial dredging), and ENR (with partial dredging) were retained for these areas; MNR and in situ treatment were eliminated.

Removal was retained for these CMAs for the reasons summarized in Section 7.2.6.6. As discussed in that section, shoreline structures such as piers will limit full removal in some locations. Shoreline structures are assumed to remain intact during remediation, and contamination left behind due to structural considerations will be addressed as part of residuals management following removal activities.

Capping was retained in conjunction with partial removal to gain appropriate clearance for future maintenance and navigation activities described in Section 7.2.5.3. For the Shallow Main Body Reach – North, the current site uses require that the elevation be maintained at approximately -40 feet MLLW, based on discussions with the Port's tenants. The maintenance depths based on reasonably anticipated future use will be revisited in remedial design. Based on the current bathymetry and maintenance depth assumptions, a cap could be placed over much of the CMA with limited partial dredging prior to cap placement. For the Shallow Main Body Reach – South, the area is not maintained at the authorized elevation of -34 feet MLLW. Based on current use (Olympic Tug and Barge is located on the west bank), this area could be reauthorized to a -30 feet MLLW navigation elevation, and a cap could be placed over most of the CMA with limited partial dredging prior to placement. Reauthorization to -30 feet

MLLW is assumed for partial dredging and capping in this FS, but actual depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process. In some deep locations, placement without partial dredging may be possible while still maintaining navigable water depths. For the FS, the technology assignment in the Shallow Main Body Reach CMA is referred to as partial dredging and capping; however, some areas may be capped without partial dredging if determined during remedial design.

ENR was retained in conjunction with partial removal to gain appropriate clearance for future maintenance and navigation activities described in Section 7.2.5.3. Although partial removal and ENR was retained in this screening, there is no alternative that incorporates this technology because there is sufficient clearance for partial removal and capping in the Shallow Main Body Reach.

MNR was eliminated due to potential for resuspension of surface and subsurface contaminated sediment from erosive forces from propwash and because future maintenance dredging could remove newly deposited sediment and placed material. In situ treatment was eliminated because other more common and effective remedial technologies are available. In particular, in situ treatment has not been used in areas with propeller scour forces similar to the EW, and there are concerns that AC, which has a lower density than native sediments, may not be stable over the long term.

7.8.4 Sill Reach

The Sill Reach is characterized by shallow bathymetry (-11 to -4 feet MLLW) and a series of three bridges. The Railroad/Emergency Access Bridge is at the southern boundary of the CMA and has limited access from low-clearance support columns and piles. To the north is the West Seattle Bridge, which has fewer access limitations due to the high deck surface and fewer support columns. Access to the area under the West Seattle Bridge is limited by the low spans of the bridges to the north and south of the West Seattle Bridge; mobilization of equipment and materials would likely need to be from the uplands. The bridge at the north end of the CMA is the Spokane Street Bridge, which has extremely low clearance and many support piles. MNR, ENR, and in situ treatment were retained for the areas under the low bridges (Railroad/Emergency Access Bridge and the Spokane Street Bridge), with removal and capping eliminated. ENR, in situ treatment, and removal were retained for the West Seattle Bridge area, with capping and MNR eliminated. However, in situ treatment was not incorporated into the alternatives for the West Seattle Bridge area because more common and effective technologies are available (e.g., removal and ENR).

Similar to the underpier areas, MNR was retained for the low bridge areas because of its practicability as compared to other remedial technologies such as removal or placement of a cap, because of the recovery potential following the remediation of adjacent areas, and because of the relatively small area under the bridges (and, therefore, relatively small contribution to site-wide risks). MNR was not retained for the West Seattle Bridge area because it is anticipated that sediments can be accessed for other remedial technologies such as ENR and removal.

ENR was retained for the entire Sill Reach. Because of limited vessel traffic, vessel propwash scour potential is considered low in this area. An ENR layer is anticipated to remain in place and accelerate natural recovery processes. Placement of ENR sand under low bridges would have to be performed in a manner similar to that described above for in situ treatment in underpier areas; placement of ENR sand in the area under the West Seattle Bridge would be staged from the uplands area, should water access be infeasible.

Removal was retained under the West Seattle Bridge, where sediments are anticipated to be accessible without using diver-assisted hydraulic dredging methods. Mobilization and staging would likely occur from the uplands. Removal may not be practicable near bridge columns, as determined during remedial design. Structures are assumed to remain intact during remediation, and contamination left behind due to structural considerations will be addressed as part of residuals management following removal activities. Removal was not retained under the low bridges because it is not technically implementable. Similar to the underpier areas, diver-assisted hydraulic dredging would be necessary due to equipment access limitations. Unlike underpier areas, the low bridges have more consolidated sediment and debris, making it infeasible to remove sediment by diver-assisted hydraulic dredging.

Capping was not retained as a remedial technology in the Sill Reach because the mudline elevation is primarily shallower than the elevation of -10 feet MLLW and, therefore, partial dredging would be required prior to capping for habitat purposes. Partial dredging and capping was not retained because the contamination depth is approximately 3 to 5 feet based on available data; therefore, partial dredging and capping would not be warranted because all or most of contaminated sediment would be removed prior to capping.

In situ treatment was retained in the Sill Reach; however, other more common and effective remedial technologies (i.e., ENR and removal) were incorporated into alternatives for stability and effectiveness considerations. Integration of in situ treatment materials (i.e., AC) into ENR sand and gravel may be considered during remedial design.

7.8.5 Junction Reach

Data indicate that surface sediment and shallow subsurface sediment (0 to 2 feet below mudline) concentrations are below the RAL set that includes a PCB RAL of 12 mg/kg OC; see Section 6); therefore, no remediation will be conducted in the Junction Reach for most alternatives. However, a 0.5-acre area has been identified for remediation for alternatives that use the PCB RAL of 7.5 mg/kg OC. For alternatives with the lower PCB RAL, removal was retained for this CMA. As discussed in Section 7.7, shoreline structures such as piers will limit full removal in some locations, and shoreline structures are assumed to remain intact during remediation.

Partial removal and capping was retained for this CMA. However, there is no alternative that incorporates this technology for this CMA because the partial dredging depth needed to gain clearance for the cap is deeper than the contamination thickness. Therefore, contamination would be removed by required partial dredging, making capping unnecessary in this CMA.

ENR was retained in conjunction with partial removal to gain clearance for future maintenance and navigation activities. However, there are no alternatives that incorporate ENR in the Junction Reach because the alternatives with the PCB RAL of 7.5 mg/kg OC focus on removal.

MNR was retained in the Junction Reach due to the low concentrations of contaminants present. However, there are no alternatives that incorporate MNR in this CMA because the alternatives with the PCB RAL of 7.5 mg/kg OC focus on removal.

In situ treatment was retained in the Junction Reach, however, other more common and effective remedial technologies (i.e., removal) were incorporated into alternatives for stability and effectiveness considerations. The use of in situ treatment materials (i.e., AC) may be considered during design.

7.8.6 Former Pier 24 Piling Field

The Former Pier 24 Piling Field CMA is a nearshore area with numerous old piles in poor condition. This FS assumes that pile removal will be a necessary component of any remedial action in this area. Removal, capping (with partial dredging), and ENR (with pile removal) were retained for this CMA, and in situ treatment and MNR were eliminated.

Removal was retained for this CMA for the reasons summarized in Section 7.2.6.6. Because the CMA is shallower than -10 feet MLLW, the area will be backfilled to grade following removal for habitat purposes. This area is targeted for habitat restoration following remediation.

Capping was retained in conjunction with partial removal to preserve elevations for habitat purposes as described in Section 7.2.5.3. Partial dredging depths are assumed to be equivalent to the cap thickness.

ENR was retained in conjunction with pile removal for this CMA. Piles could be pulled or cut at mudline prior to placement of ENR. ENR material would be placed at a stable grade (e.g., 3H:1V) and be used in areas with moderate contaminant concentrations. Although ENR is retained for consideration during design, ENR is not incorporated into the remedial alternatives because of the potential for high concentrations in surface sediment following pile removal.

MNR and in situ treatment were eliminated for this CMA due to the potential for high contaminant concentrations following pile removal.

7.8.7 Nearshore Areas not Used as Berths

Nearshore areas not used as berths include T-25 Nearshore, T-30 Nearshore, Slip 27 Nearshore/Mound Area, and Coast Guard Nearshore. All of these CMAs include nearshore sediments and accessible sloped banks. Removal was retained for T-25 Nearshore and T-30 Nearshore, with capping, ENR, MNR, and in situ treatment eliminated. Capping (with partial dredging) was retained for Slip 27 Nearshore/Mound Area and Coast Guard Nearshore with removal, ENR, MNR, and in situ treatment eliminated.

Removal was retained for T-25 Nearshore and T-30 Nearshore for the reasons summarized in Section 7.2.6.6. Engineered shorelines could limit full removal in some locations. Areas shallower than -10 feet MLLW will be backfilled to grade following removal for habitat purposes. Removal was eliminated for the Slip 27 Nearshore/Mound Area and the Coast Guard Nearshore because they have cores exhibiting deep contamination (13 feet thick or greater for both CMAs) and engineered shorelines, making full removal impracticable.

Capping was retained in conjunction with partial removal for Slip 27 Nearshore/Mound Area and the Coast Guard Nearshore to preserve elevations for habitat purposes as described in Section 7.2.5.3. Partial dredging depths are assumed to be equivalent to the cap thickness in areas shallower than -10 feet MLLW. Capping was not retained for T-25 Nearshore and T-30 Nearshore CMAs because they have thinner contamination (approximately 5 feet or less for both areas); therefore, most contamination would be removed by partial dredging, making capping unnecessary.

MNR and ENR were eliminated for these CMAs due to the concentrations in surface sediment and/or slope stability requirements. In situ treatment was also eliminated because other more common and effective remedial technologies are available.

7.8.8 Communication Cable Crossing

The Communication Cable Crossing CMA traverses the EW OU at Stations 1400 to 2000. Portions of the CMA are in the federal navigation channel and berth areas and, therefore, have navigation elevation requirements. Removal and ENR (with partial dredging) were retained for these areas; capping, MNR, and in situ treatment were eliminated.

The limits of removal will need to be restricted to avoid damage to the communication cable and supporting infrastructure (i.e., rock ballast structure). For this reason, the removal alternative is referred to as "removal to the maximum extent practicable and backfill." Backfill is intended to provide additional protectiveness for any buried contamination left behind; sufficient clearance may not be present to construct a full isolation cap. Backfill may not be necessary if all or most contamination is removed in this area, as determined during design.

ENR was retained in conjunction with partial removal in this CMA to gain appropriate clearance to achieve authorized navigation depths. Similar to the adjacent Deep Main Body – North CMA (Section 7.8.1), ENR was incorporated into the remedial alternatives as ENR-nav, which would include additional measures to mitigate the impact of vessel scour on surface sediment chemistry. For this FS, it is assumed to be a thicker layer of ENR (average thickness of 18 inches as opposed to 9 inches in other ENR areas), which would mitigate the impact of scour by increasing the scour depth necessary to impact underlying sediment and increase the mass of clean sediment to mix with underlying sediment. Furthermore, this FS assumes that ENR-nav would only be employed in areas with relatively low sediment concentrations (e.g., between RALs and 2x RALs) to further reduce the impact of potential mixing of ENR-nav material with underlying sediment.

Capping was not retained in this CMA because the communication cable crossing structure limits partial removal depth required to gain navigational clearance once a full cap was placed.

MNR was eliminated in this CMA due to the potential for resuspension of surface and subsurface contaminated sediment from erosive forces such as propwash, and because future maintenance dredging could remove newly deposited sediment. In situ treatment was also eliminated because other more common and effective remedial technologies are available. In particular, in situ treatment has not been used in areas with propeller scour forces similar to the EW, and there are concerns that AC, which has a lower density than native sediments, may not be stable over the long term.

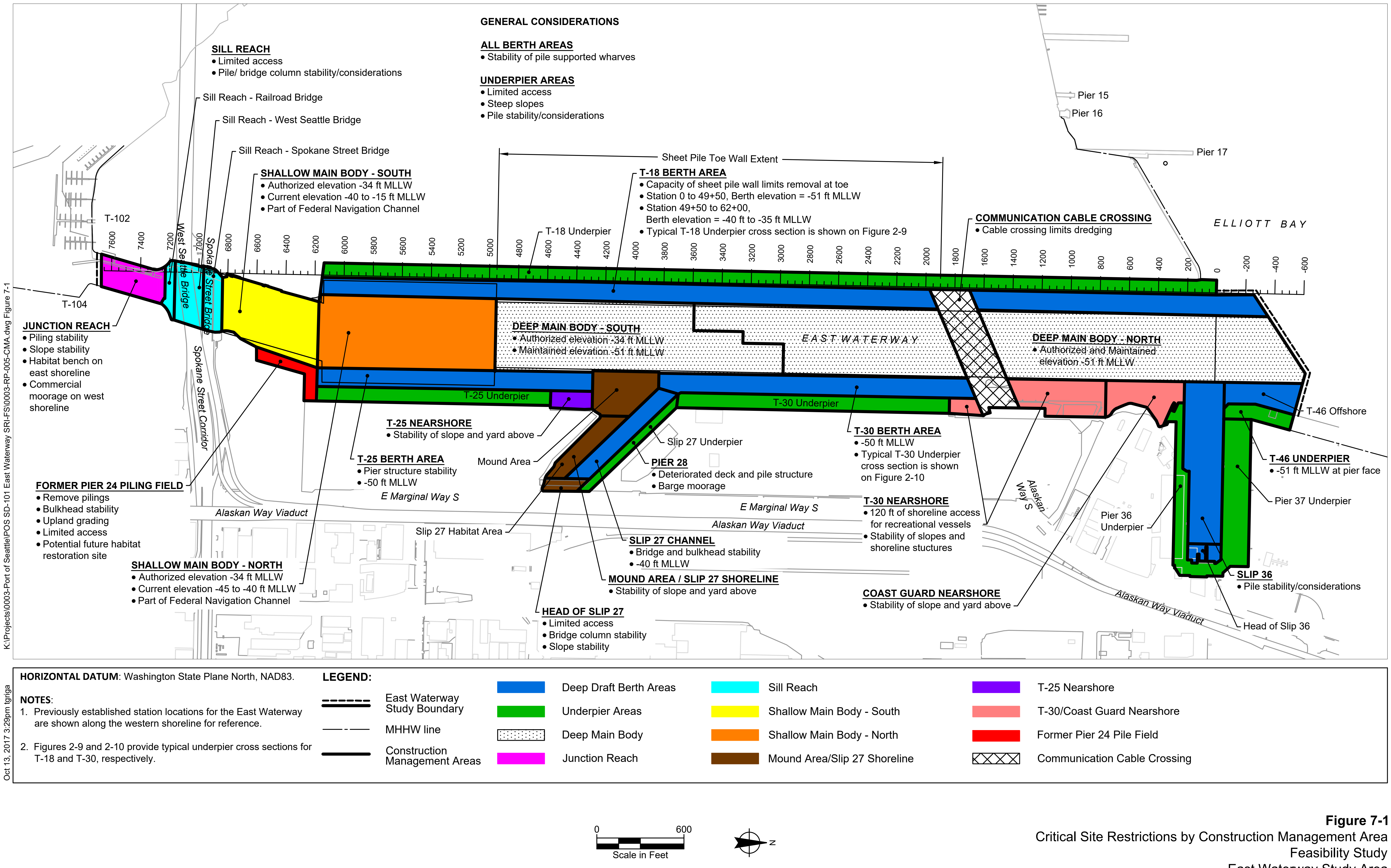
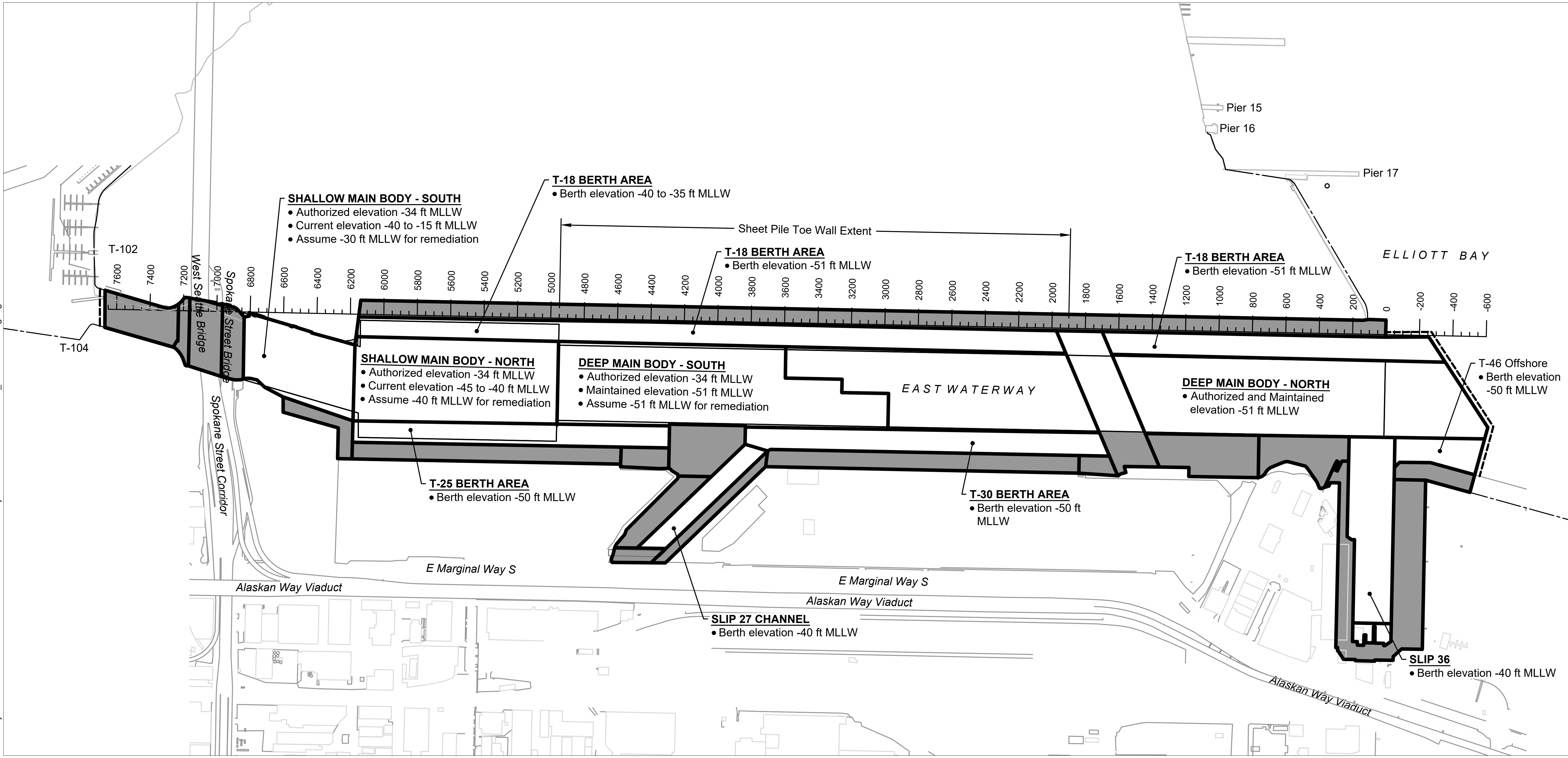


Figure 7-1
Critical Site Restrictions by Construction Management Area
Feasibility Study
East Waterway Study Area



K:\Projects\0003-Port of Seattle\POS SD-101 East Waterway SRI-FS\0003-RP-011-Nav_Berth Elevs.dwg Figure 7-2

Oct 13, 2017 3:32pm tgriga

HORIZONTAL DATUM: Washington State Plane North, NAD83.

NOTES:
1. Previously established station locations for the East Waterway are shown along the western shoreline for reference.
2. Figures 2-9 and 2-10 provide typical underpier cross sections for T-18 and T-30, respectively.
3. In the Shallow Main Body- South, the navigation channel may require reauthorization or deauthorization (depending on the alternative) because the remediation elevation is higher than authorized navigation elevation. See description of alternatives in Section 8.

LEGEND:
- East Waterway Study Boundary
- MHHW line
- Construction Management Areas (CMA)
- CMA Not in Navigation Channel or Berthing Area

0 600
Scale in Feet

Figure 7-2
Navigation and Berth Elevations
Feasibility Study
East Waterway Study Area

8 DEVELOPMENT OF REMEDIAL ALTERNATIVES

This section presents the assembly and description of alternatives for cleanup of the EW OU. The alternatives are assembled in a manner consistent with CERCLA guidance (EPA 1988). With the exception of the No Action alternative, each of the alternatives is designed to achieve the PRGs, or as close as practicable to the PRGs[89] (the performance of the alternatives is discussed in detail in Section 9). All other alternatives are referred to as the "action alternatives."

The preliminary alternatives were assembled and screened in coordination with EPA, as presented in Appendix L. The alternatives are based on the RALs and remediation footprints developed in Section 6 and the remedial technologies (applicable to CMAs) retained in Section 7, with the objective of screening a wide range of technically feasible options and a variety of remedial technologies. The preliminary alternatives in Appendix L were screened for effectiveness (both long- and short-term), implementability (from technical and administrative feasibility perspectives), and costs per CERCLA guidance. The selected remedial alternatives are described in Section 8.2 and carried forward for detailed and comparative analysis in Sections 9 and 10 of the FS.

Section 8.1 discusses the common assumptions used for the action alternatives, Section 8.2 describes in detail the specific elements of the alternatives, and Section 8.3 discusses key uncertainties in the assumptions used to develop the action alternatives.

8.1 Common Elements for all Action Alternatives

This section provides assumptions used in the development of the action alternatives. It includes common engineering assumptions (Section 8.1.1), technology-specific engineering assumptions (Section 8.1.2), remedial design investigations and evaluations (Section 8.1.3), monitoring (Section 8.1.4), adaptive management (Section 8.1.5), and project sequencing (Section 8.1.6).

[89] Applies to PRGs based on natural background sediment concentrations.

8.1.1 Engineering Assumptions

8.1.1.1 Staging

Staging for sediment remediation projects refers to upland operational areas that support material and equipment handling to and from the in-water project location. Upland staging areas are required to support equipment and material transfers to barges, transloading of dredged sediment for upland disposal, and land-based excavation operations.

For planning purposes, this FS assumes that suitable land will be available in the vicinity of the EW OU for staging and support activities. Specific staging areas have not been identified, and only rough assumptions have been made about specific staging area requirements. The cost estimate in Appendix E assumes that staging activities are incorporated into the mobilization/demobilization and site preparation costs for the project.

8.1.1.2 Pile and Debris Removal

The FS assumes that most dolphins, piles, and in-water structures will remain in place during remediation. Offsets will be needed adjacent to these structures to avoid any structural damage or impacts to structure stability. The offset requirements will be determined during remdial design. However, derelict piling and piers may be removed during remediation as determined during remedial design. Piles in removal areas will be extracted before dredging or removed during dredging. Piles in partial dredging and capping areas may be fully removed or partially removed and covered with an engineered cap as determined in design. For cost estimating, all action alternatives assume that 1,000 piles will be removed from the waterway, which is the approximate number of piles in the Pier 24 Piling Field (Station 6400 East).

Debris of varying size and spatial density may be present in portions of the EW OU. The amount of debris is not known at this time; however, the amount of debris is likely to be less in areas that have been deepened or maintenance dredged in the last several decades (e.g., portions of the Deep Main Body Reach). Standard practice in environmental dredging operations is to remove or “sweep” for debris (e.g., logs, concrete) concurrent with sediment removal. The debris is then barged and offloaded at a transloading facility for subsequent shipment to an upland landfill or for potential recycling (i.e., beneficial reuse). Side-scan sonar surveys, magnetometer surveys, and other methods may be used to assess the presence of debris. If no debris is detected, a debris removal pass may not be required. Debris removal was incorporated into the cost estimate by considering reduced efficiency during debris removal when estimating the removal production rate (and resultant unit costs). The cost estimate assumes that no debris removal would be necessary in ENR, in situ treatment, or MNR areas. This FS assumes that in situ treatment and ENR material would be effectively placed without removing debris, and debris would not require removal prior to placement. Debris removal could have a large impact on costs and dredging effectiveness, particularly for underpier dredging. Although the amount of underpier debris has not been quantified, significant debris has been observed during maintenance dredging next to piers (e.g., at T-18).

8.1.1.3 Transloading and Upland Disposal

The availability and capacity of transloading and transportation infrastructure to manage dredged material is an important factor in the production or dredging rate. This FS assumes that transloading would occur at a nearby EPA–approved facility, or that a transloading facility would be constructed in the vicinity of the EW OU. Because the availability of an existing transload facility is not assured, costs for the construction and maintenance of a transload facility are included in mobilization costs for the alternatives (Appendix E).

Transloading and transportation could occur by various methods, such as loading directly to rail and then transporting directly to the disposal facility, loading directly to truck and then trucking to the disposal facility, or a combination of truck and rail. Considerations for selecting the location of the transloading facility include proximity to the site and rail, existing infrastructure and site use, throughput capacity, permitting requirements, odor, noise, water management, and navigation restrictions. For calculating short-term effectiveness of the alternatives, Appendix I assumes that contaminated sediment would be barged to a nearby existing or newly constructed transloading facility and sent by rail to a landfill; no additional transportation is assumed to occur at the landfill facility. The estimated cost of $70/ton of sediment includes transloading, water management at a transloading facility, truck transportation to a rail facility, rail transport to a landfill, and offloading and disposal of material to a permitted Subtitle D landfill (see Appendix E). If an existing transload facility is used, then the total transload and disposal costs are expected to be similar to those in the FS cost estimate. In this case, the mobilization costs would go down because the transload facility would not need to be constructed specifically for the EW cleanup, but the unit transloading costs would go up to incorporate up-front costs paid to the entity owning/operating the transloading facility for mobilization, permitting, and land lease.

8.1.1.4 Water Management

For mechanical dredging, this FS assumes that dredged sediment will initially be dewatered on the dredge scows with water discharged back to the EW OU within the dredging area after appropriate on-board processing. It is assumed that the dredge scows will be equipped with appropriate BMPs (e.g., hay bales, weir systems, and filtration) to filter runoff as necessary to maintain compliance with applicable water quality criteria established for the dredging operations. If water quality exceedances occur during remedial activities, construction operations may be suspended until adequate BMPs are in place to achieve water quality criteria. Gravity drainage consolidates the sediment load, reduces potential releases during offloading, and reduces the volume of water that otherwise would need to be managed elsewhere (e.g., transloading facility or landfill). Water management costs (per the methods outlined above) during mechanical dredging are included in the unit cost for dredging of $27/cy. As described in Section 7.5.1.1, water quality criteria at recent dredging projects (EW T-18 Maintenance Dredging and the LDW Slip 4 and T-117 EAAs) have been met using gravity dewatering through filter media. However, additional treatment of dewatering effluent may be considered during remedial design. If gravity dewatering is not allowed at the site, water treatment costs will be higher and dredging production rates will be lower.

For underpier diver-assisted hydraulic dredging, this FS assumes that water management will be performed by constructing a water treatment system on a barge. The water treatment system would consist of a series of tanks and filters to treat dewatered liquid and contaminants from dredged material. Clean water would be discharged back into the waterway. The cost for dewatering of hydraulically dredged sediment is estimated to be $400/cy of sediment.

Water management is also a key component of dredged material transloading operations. Stormwater and drainage from sediments generated within the confines of 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 to the EW. Discharge into the EW must comply with the substantive requirements of the National Pollutant Discharge Elimination System permitting regulations (WAC 173-220), as administered by Ecology.

Several landfills are permitted to receive wet sediment (i.e., that does not pass the paint filter test), including two regional RCRA Subtitle D landfills (Allied Waste Inc. in Roosevelt, Washington and Waste Management in Arlington, Oregon) and another regional landfill permitted to accept wet sediment (Weyerhaeuser Regional Landfill in Castle Rock, Washington). Once transferred to lined shipping containers, any additional consolidation of sediment and corresponding accumulations of free water are managed at the landfill facility.

8.1.1.5 Sea Level Rise

Climate change is expected to continue to increase sea levels over the next few hundred years (NRC 2012; National Assessment Synthesis Team 2000; Ecology 2006), and this is a design consideration for cleaning up high elevation (i.e., nearshore and intertidal) areas of the EW OU. The predicted sea level rise in the vicinity of the EW OU is approximately 4 to 56 inches over the next century, with a mean projection of 24 inches (NRC 2012). Sea level rise would result in a corresponding shift in the elevations that define intertidal habitat and regulatory boundaries. Further, the design of engineered shoreline infrastructure (e.g., shoreline caps) may need to address the long-term effects of sea level rise. Sea level may factor into certain remedial design elements in intertidal areas, but is not considered to be a significant factor in the selection or the analysis of the alternatives in this FS since it will likely impact all alternatives equally.

8.1.1.6 Dredge Area and Volume Estimates

The area requiring remediation is based on samples with surface and shallow subsurface sediment concentrations exceeding the alternative's RALs. The method for determining the area requiring remediation is presented in Section 6.

Removal and placement volumes are key parameters for estimating costs and construction durations for the alternatives. The method for estimating removal volume in each area is detailed in Appendix F. The general approach for estimating removal volume was to estimate the thickness of sediment above the appropriate RAL set at every core location to establish an estimated neatline for the dredge prism for each RAL set. The neatline volume was calculated in CAD by multiplying neatline dredge depth by area for removal areas. Total removal volumes were then estimated by multiplying the neatline volume by a constructability factor of 1.5 (in most areas) to include provisions for stable dredge cut side slopes, allowable over-depth, slumping of sediments between dredge units, and missed inventory (Palermo 2009). Note that dredging to remove contaminants exceeding RALs (for any of the RAL sets) would also remove all contaminants exceeding SQS based on existing core data.

The approach to estimating neatline volume varied depending on location in the EW OU. In the Deep and Shallow Main Body Reaches and adjacent berthing areas (T-18 Berthing Area, T-25 Berthing Area, and T-30 Berthing Area), the neatline volume of contaminated sediment was estimated by interpolating with a triangular irregular network (TIN) based on the contaminated thickness of the appropriate RAL set at the location of each core in CAD. Further refinement of the TIN will be completed during remedial design to develop the dredge prism.

The neatline volumes for smaller open-water CMAs (i.e., Sill Reach, Former Pier 24 Piling Field, T-25 Nearshore, Mound Area, Slip 27 Channel, T-30 Nearshore, T-46 Offshore, and Slip 36) were established by estimating a contaminated thickness based on cores in and near the CMAs, and multiplying by area. As discussed in Appendix F, the TIN was not used in these smaller, open-water CMAs because the assumed contaminated sediment thickness at the MHHW boundary would have a larger effect on volumes than actual core data, therefore making the TIN less accurate.

In the Mound Area, Slip 27 Head and Shoreline, and the Coast Guard Nearshore CMAs, the dredging depth was assumed to be 5 feet for the FS (plus the constructability factor of 1.5 to account for overdredging, etc.), to accommodate a 5-foot cap while restoring the surface elevations to the existing grade.

Due to uncertainties with existing conditions in the Communication Cable Crossing CMA because of lack of as-built or cable survey information, the neatline volume assumes a sediment thickness of 3 feet to the top of the cable's armored trench, multiplied by the associated dredging area. Additional surveys of this area will be required during remedial design.

The neatline volumes in underpier areas were estimated by analyzing underpier cross sections using jet probe data. The jet probe data were collected during underpier surveys in 1998 and 2000 at T-18, T-25, and T-30 to measure the lateral extent of sediment in underpier areas and sediment thickness along transects (Sunchasers 2000). Estimations were made of the cross-sectional area of soft sediment for cross sections along the piers. The cross-sectional area of soft sediment was multiplied by the representative pier length to estimate the total volume of soft sediment. The area of riprap without sediment was removed from the potential remediation area. Finally, the cross-sectional area of sediment was assumed to be the same, resulting in an assumed uniform average thickness of 2.3 feet of sediment. The area above RALs in underpier areas was estimated based on Thiessen polygons, which include polygons associated with underpier samples and adjacent open-water samples (see Appendix F for additional detail).

8.1.1.7 Material Placement Volume Estimates

The placement volumes were calculated by the following assumptions:

- RMC was assumed to be applied as a 9-inch average thickness over all open-water dredging areas plus the interior unremediated areas (i.e., the open-water unremediated areas surrounded by dredging areas; see Figure 6-6). A 9-inch thickness has been demonstrated to be effective at other sites for RMC and anti-degradation cover, and is expected to be effective in the EW considering estimates of site-specific dredge residuals (see Appendix B, Part 5). RMC is assumed to be placed for costing purposes, but is contingent on post-dredge sampling and monitoring results.
- Backfill to original grade was assumed to be applied to all open-water dredging areas shallower than -10 feet MLLW, and to the Communication Cable Crossing. The backfill volume was assumed to equal the dredging volume in these areas. Areas shallower than -10 feet MLLW are assumed to be returned to grade to preserve

shallow water areas that serve as important habitat; alternative post-construction elevations may be selected in design to preserve or increase habitat value. In the Communication Cable Crossing CMA, the thickness of backfill will be re-evaluated during design and will be dependent on the practicable dredging depth in the area. For example, if removal of all sediment exceeding RALs is practicable, then backfill may not be necessary, whereas if significant contamination remains in place following dredging, then backfill would be necessary to reduce the chance of recontamination of surface sediment.

- Capping was assumed to be a total of 5 feet thick in all locations, consisting of a 2.5-foot isolation layer, a 1.0-foot filter layer, and a 1.5-foot armor layer. This is a reasonable capping thickness to be assumed site-wide, based on propwash modeling and contaminant transport modeling (see Appendix D); however, the cap thickness may be refined during remedial design, based on location–specific conditions.
- ENR in the Sill Reach (outside of navigation and berthing areas (ENR-sill) was assumed to be applied as a 9-inch average thickness of sand, similar to RMC.
- ENR inside of navigation and berthing areas (ENR-nav) was assumed to be applied as an 18-inch average thickness of sand.
- In situ treatment was assumed to be applied in underpier areas in a 3-inch thickness (consistent with the Bremerton pilot study (see Section 7.2.7.1), with an appropriate percent of AC (between 2% and 5%) to mix into the bioturbation zone, as determined during remedial design.

8.1.1.8 Construction Timeframe

The Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15 (USACE 2015). However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15, to avoid conflicts with tribal netfishing, potential adverse effects to migrating salmon, and for consistency with commonly accepted construction window of upstream waters (i.e., the LDW construction window is October 1 to February 15). The FS conservatively estimates that the total number of construction days for a typical construction season is 100 days/season. This estimate accounts for 37 non-construction days, consisting of weekends, holidays, and down time within the October 1 to February 15 timeframe. Tribal netfishing does occur later than

October 1 and will require tribal coordination of construction timing, which could further shorten the timeframe assumed. It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15); however, a coordination plan between the potentially responsible parties, EPA, and affected tribes may be necessary in order to reduce possibilities of construction activities needing to be stopped during the tribal netfisheries. With this longer construction window, the upper end of the number of work days in a construction season could increase to around 150 days/season. Any realized increase in the construction window between 100 to 150 days per year would reduce the total number of construction years by approximately 2 years for all the action alternatives.

The FS assumes that open-water work would be performed in one 12-hour shift per day, and underpier work would be performed in one 8-hour shift per day. The dredge production rate in the EW is limited by a number of constraints including available transloading infrastructure, the need to work around active port operations (i.e., berthed and navigating vessels), and stringent water quality requirements.

Detailed phasing for the EW cleanup will be determined during remedial design. For the FS, the construction timeframe calculation assumes that one open-water operation and one underpier operation would operate concurrently. Following several seasons of removal, placement operations (capping, ENR, or in situ treatment) could happen concurrently with dredging operations, assuming that sufficient distance and controls would be used to avoid contamination from dredging residuals (e.g., if dredging operations start in the south part of the site and move northward, then capping, ENR, and in situ treatment placement could occur in the south portion of the site while dredging occurs in the north portion of the site). Finally, RMC placement is assumed to occur throughout the waterway following all dredging and other placement operations to minimize potential recontamination of RMC during construction (Appendix E).

The average production rates for various activities for construction timeframe estimates are as follows (basis presented in Appendix E):

- Open-water dredging: 1,100 cy/day
- Limited access dredging (under the West Seattle Bridge): 270 cy/day

- Underpier dredging: 40 cy/day
- Sand and gravel placement (capping isolation and filter layers, ENR, RMC): 940 cy/day
- Cap armor placement: 560 cy/day
- Underpier and low bridge placement (in situ treatment and ENR): 60 cy/day

8.1.2 Technology-specific Engineering Assumptions

This section presents the assumptions that were used in applying each remedial technology for the purpose of estimating cleanup timeframes and costs for this FS. Uncertainties associated with performance of remedial technologies and a discussion of how these uncertainties have been addressed in this FS are included in Section 8.3.

8.1.2.1 Removal

Removal technologies used in the FS rely on different mechanical equipment in open-water areas and diver-assisted hydraulic dredging under piers. These technologies are described below.

Mechanical Dredging

For this FS, mechanical dredging using a clamshell dredge mounted on a derrick barge is assumed in all open-water areas. In difficult-to-access areas (e.g., West Seattle Bridge), alternate removal methods such as excavation using upland equipment could be considered. Mechanical dredging in open-water areas is assumed to cost $27/cy based on recent project experience, assuming $30,000/day for equipment and labor and a production rate of 1,100 cy/day. This estimate includes barge dewatering and delivery of contaminated sediment to the transload facility. Barge sizes vary, but a typical barge for a project conducted in the EW would have a maximum capacity of about 2,000 tons (3,000 cy). The turnaround time for transport, offload, and return to the dredge site could be several days, depending on the location of the offloading facility.

Dredging under the West Seattle Bridge would be more expensive due to lack of access from the water and limited space for maneuvering. The cost for dredging in this location was assumed to be $119/cy to account for limited production rates and trucking to the transload facility.

In practice, the dredging near piers, engineered slopes, the cable crossing, and other structures may not be able to remove all contaminated sediment without compromising structures or slopes. Therefore, the FS assumes that dredging in areas adjacent to piers and slopes would occur to the maximum extent practicable, and remaining contamination would be addressed as part of residuals management.

Diver-assisted Hydraulic Dredging Under Piers

Dredging of underpier areas will have access limitations that preclude the use of traditional marine-based dredging or barge-mounted excavation equipment. In these areas, removal is assumed to be performed by diver-assisted hydraulic dredging since mechanical dredging may pose unacceptable risks for damaging the existing structures and/or underpier riprap slopes.

Removing contaminated sediment from underpier locations presents significant engineering and construction challenges from the stability of piles, potential presence of debris, hard surfaces, or engineered slopes (e.g., riprap). It is not possible to remove 100% of the contaminated sediment from underpier areas because contaminated sediment is present in the interstices of engineered riprap slopes. Furthermore, as discussed in Section 7.2.6.3, diving presents worker safety challenges; the risks for injury and death during construction increase with every hour of diver assistance for hydraulic dredging activities. Underpier areas are adjacent to active berthing areas and diving schedules are likely to be significantly impacted by waterway activities. Similarly, some business interruption will occur as a result of diver-assisted hydraulic dredging because of restricted access to areas where divers are performing underwater work.

The costs for diver-assisted hydraulic dredging are estimated to be $600/cy based on $24,000/day for equipment and labor at a production rate of 40 cy/day, not including water management and treatment. There is high uncertainty in this unit cost; recent project experience shows that costs can be as high as $1,100/cy. Hydraulic dredging also generates a large amount of water requiring treatment. As previously discussed in Section 8.1.1.4, costs for dewatering hydraulically dredged sediment are approximately $400/cy. Mobilization and demobilization costs for dredging and dewatering equipment, diving equipment, and diver safety plans and procedures are estimated to be $250,000 per construction season.

Dredge Residuals Management

As discussed in Section 7.2.6.5, dredging residuals include undisturbed residuals (missed inventory) and generated residuals (re-suspended during dredging).

Dredging typically releases contaminated sediment (referred to as residuals) that settles back onto the dredged surface or is transported outside the dredged area (USACE 2008b; Bridges et al. 2010; Patmont and Palermo 2007). Depending on location-specific conditions, these residuals will contain elevated concentrations of risk driver COCs. To manage residuals, numerous design and operational controls will be evaluated during remedial design.

As discussed in Section 8.1.1.7, residuals management is assumed to include thin-layer placement of 9 inches average of RMC sand layer to address elevated post-dredge concentrations, which could also act as a habitat enhancement layer. During construction, this layer will be placed in areas where post-dredge monitoring shows surface sediment concentrations are above action levels, either in the removal footprint (remediated area) or unremediated area. This RMC sand layer would also serve as anti-degradation cover to comply with the substantive requirements of the state's SMS antidegradation policy (WAC 173-204-120), as necessary. For project sequencing, RMC placement is assumed to occur following all removal and placement activities. RMC is assumed to cost $20/cy for sand purchase and $26/cy for placement, consistent with recent project experience.

Addressing undisturbed residuals is important for achieving dredging goals. Undisturbed residuals will be investigated during post-dredge sampling and addressed as part of contingency actions, such as re-dredging or RMC placement. Additional dredge passes may also be used as part of residuals management. The need and rationale for additional dredge passes will be determined during design, taking into account pre- and post-dredge sediment sampling data and other residual management strategies (e.g., RMC).

8.1.2.2 Partial Dredging and Isolation Capping

For this FS, construction of conventional caps using appropriate material gradations (isolation layer, filter layer, and armor layer) has been assumed. The gradation of material selected for capping depends on factors such as habitat, erosion, and scour potential. Based on preliminary cap modeling in Appendix D, a 5-foot-thick cap has been assumed, representing 1.5 feet of armor, 1 foot of filter material, and 2.5 feet of isolation material. The EW OU is an active waterway used by large vessels with relatively large propwash forces, which may require the use of armoring in many locations. The cap design will be further refined in remedial design, and could include the use of thinner caps amended with sorptive or reactive materials where needed to meet breakthrough performance requirements, refinement of location-specific propwash forces and armoring needs, and a surface habitat layer to support benthic organism and fish communities.

The assumed restrictions on capping associated with water depths in the navigation channel, berthing areas, and habitat areas are provided in Section 7.6. Analysis of the EW OU shows that most areas would require partial dredging prior to capping to comply with elevation requirements. Partial dredging would be performed in the same manner as dredging (previously described in Section 8.1.2.1), with cap placement serving as the RMC. The partial dredging depths are described in Section 7.6.

A key consideration for partial dredging and capping is the amount of dredging required to accommodate a cap with enough post-construction vertical clearance to allow for future maintenance dredging in navigation areas. In one area (Shallow Main Body – South [Stations 6200 to 6850]), the currently authorized navigational depth may not be operationally required based on current and anticipated future site use. Therefore, an option to construct the top of the cap above the currently authorized elevation is included in the FS. This would require a change to the authorization of the federal navigation channel. Reauthorization to -30 feet MLLW is assumed for partial dredging and capping in this FS, but actual depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process. Reauthorization would be initiated after the ROD in conjunction with remedial design to obtain reauthorization prior to capping the Shallow Main Body – South.

Cost assumptions for capping assume that material from a local quarry is transported by barge to the site. For the filter and isolation layers, capping is assumed to cost $20/cy for material purchase and $26/cy for placement. For the armor layer, capping is assumed to cost $35/cy for material purchase and $43/cy for placement, consistent with recent project experience.

8.1.2.3 In situ Treatment

In situ treatment, as described in Section 7.2.7.1, is the placement of an amendment material such as AC to reduce the bioavailability of contaminants in sediments. The amendment material is often placed as part of a clay, sand, and/or gravel matrix to deliver the amendment to the sediments in a reasonably stable lift. In situ treatment is considered for underpier areas because it includes a relatively small thickness of placement material (i.e., less than ENR or an isolation cap) and, therefore, is appropriate for access-limited areas and areas with steep slopes and pile stability considerations.

This FS assumes that in situ treatment would be performed similar to the underpier areas of the Bremerton Naval Shipyard (see Section 7.2.7.1). In this case, a 3-inch-thick layer of material (to produce between 2% and 5% AC in the top 10 cm) was placed via a Telebelt®. The cost for in situ treatment under piers is assumed to be $500/cy for material purchase (e.g., AquaGate+PAC™ composite aggregate system) and $400/cy for placement based on the Bremerton Naval Shipyard Pilot (0.5 acre), with adjustments made for economy of scale for the larger EW underpier areas (12 to 13 acres of in situ treatment area, depending on the alternative).[90]

The effectiveness of in situ treatment depends on multiple factors, including chemical interactions in sediment and the effect of sources from outfalls and open-water exchange. To account for these uncertainties, 15% of underpier in situ treatment areas are assumed to require additional remediation at $4 million per acre by an unspecified remedial technology. Costs are approximately equal to the base capital cost for diver-assisted hydraulic dredging under piers based on an average neatline dredge depth of 2.3 feet (Appendix F) and the unit

[90] The costs of the Bremerton Naval Shipyard Pilot (Chadwick et al. 2014) were reduced by about 75% for economy of scale.

costs for dredging, water management and disposal (Appendix E), without additional costs for construction contingencies, design, project management, etc.

8.1.2.4 Enhanced Natural Recovery

ENR consists of applying a thin layer of sandy material to accelerate the natural recovery processes of mixing and burial. This FS assumes that ENR outside of navigation and berthing areas (ENR in the Sill Reach, called ENR-sill) would involve spreading an average of 9 inches of sand. ENR inside of navigation and berthing areas (ENR-nav) would involve spreading an average of 18 inches of sand. ENR thicknesses and material specifications would be revisited during remedial design.

Material is assumed to be imported from off site, but could be obtained from local maintenance dredging as discussed for in Section 7.2.5.3. The composition of ENR will depend on additional evaluation during remedial design; it may include habitat mix or scour mitigation specifications to increase sediment stability and enhance habitat, or AC to reduce bioavailability of residual contamination (i.e., designed similar to in situ treatment). However, costs for this FS assume that ENR consists of placement of sand only.

In order to preclude treatment material from being removed during future maintenance dredging operations, partial dredging would be required in some ENR-nav areas to gain sufficient clearance. The clearance would be sufficient to prevent ENR material from being removed during future navigation dredging activities. The assumed restrictions on thin-layer placement and capping associated with water depths in the navigation channel, berthing areas, and habitat areas are provided in Section 7.6. Analysis of the EW OU shows that about half of the areas would require partial dredging prior to ENR-nav placement to attain sufficient clearance for potential future maintenance dredging. Partial dredging prior to ENR-nav placement would be performed in the same manner as dredging, as described in Section 8.1.2.2. The partial dredging depths are described in Section 7.6.

Placement of ENR material in difficult-to-access areas (e.g., low bridge areas of the Sill Reach) would be performed the method previously described for placement of in situ treatment material under piers. ENR is assumed to cost $20/cy for sand purchase, $26/cy for placement in open-water areas, and $400/cy under the low bridges of the Sill Reach.

The effectiveness of ENR depends on multiple factors, including sedimentation rate, concentrations of contaminants of incoming sediment, and sediment stability. To account for these uncertainties, 15% of ENR areas are assumed to require additional remediation at $1 million per acre in open-water areas, and $4 million per acre under low bridges by an unspecified remedial technology (costs are approximate equal to the base capital cost for dredging in these areas based on an average neatline dredge depth of 3.5 feet in open-water areas and 2.3 feet in underpier areas, times the unit costs for dredging and disposal, without additional costs for construction contingencies, design, project management, etc.).

8.1.2.5 Monitored Natural Recovery

MNR uses an intensive monitoring program to track success of achieving set chemical concentration reduction over a set time, and a decision framework for implementing contingency actions if needed (adaptive management; EPA 2005).

As discussed in Section 7.7, MNR was retained in underpier areas and under low bridges for several reasons. First, most other remediation technologies will be challenging to implement under piers; therefore, MNR is significantly more practicable than other forms of remediation. Second, these areas may have high recovery potential following the remediation of adjacent open-water areas because of sediment exchange between these areas. The best estimate used in this FS is that 25% of underpier sediment exchanges with open-water areas every 5 years (see Section 5.3.4). Third, these areas have relatively small spatial extent and, therefore, contribute less to site-wide risks (e.g., see Appendix J sensitivity results for Alternative 1A(12)) from bioaccumulative compounds.

Multiple lines of evidence support the limited areas that are considered for MNR in the FS. Although there were no geochronological cores located directly under the piers and low bridges, geochronological cores from adjacent areas are assumed to be sufficient to estimate sedimentation rates in these areas (Appendix J). In addition, the exchange of underpier sediment with open-water areas is a key consideration for MNR under the piers. The proximity of underpier sediment to berthing operations indicate that underpier sediment is subject to resuspension by propwash forces; however, vessel scour patterns indicate that resuspended sediment from adjacent berthing areas are depositing in the underpier. The estimated sedimentation rates and underpier exchange rates are factored into the estimated effectiveness of MNR presented in Appendix J and Section 9.4.

This FS assumes that area-specific MNR sampling would occur at prescribed intervals (see Appendix G). Adaptive management (i.e., contingency actions) may occur at any time during the monitoring period. Contingency actions for areas that do not achieve RALs may include active remediation, additional investigation, and further monitoring, and are included as separate line items in the cost estimate.

The effectiveness of MNR depends on multiple factors, including sedimentation rate, concentrations of contaminants of incoming sediment, sediment exchange with open-water areas, and sediment stability. To account for uncertainties in these factors, 15% of MNR areas are assumed to require additional remediation at $4 million per acre by an unspecified remedial technology (costs are approximate equal to the base capital cost for dredging under piers and low bridges based on an average neatline dredge depth of 2.3 feet and the unit costs for dredging, water management, and disposal, without additional costs for construction contingencies, design, project management, etc.]).

8.1.2.6 Institutional Controls

The two major types of institutional controls considered for this FS are: 1) proprietary controls, typically as environmental covenants enforceable by EPA or the property owner; and 2) informational devices. Informational devices are further split into two primary components: a) monitoring and notification of waterway users, including the state's Environmental Covenants Registry; and b) seafood consumption advisories, public outreach, and education. These are discussed in Section 7.2.2.

All types of institutional controls apply to all action alternatives. Seafood consumption advisories, public outreach, and education would likely be similar in scope for all action alternatives. Proprietary controls and monitoring and notification of waterway users will vary in scope depending on the amount of contamination left on site. The degree to which each of these institutional controls is expected to be used for each alternative is discussed in Section 8.3.

Costs for institutional controls are incorporated into the cost estimate for each action alternative as part of total project management and agency review/oversight costs, which are assumed to be 1% of total construction costs (project management), and $120,000/year for 25 years following construction for agency review/oversight (Appendix E).

8.1.3 Remedial Design

Remedial design investigations include location-specific sampling or testing for the purpose of refining the design and engineering assumptions for the selected remedy. The EW OU has been studied extensively for the SRI/FS, previous remediation projects, and past development projects. Therefore, much of the information needed for remedial design is already available. However, some additional investigations may be necessary during remedial design to complete the design process, refine the selected remedial technology footprints, and evaluate performance potential. Remedial design investigations may be needed to accomplish the following:

- Refine the nature and extent of contaminated sediment in EW OU being considered for remediation, including the vertical and horizontal extent of contamination above the RALs as needed to inform design.
- Use available data to conduct additional evaluations to calculate anticipated stability of native sediments or placement materials such as sand cover or cap armoring.
- Collect bathymetric data to evaluate current elevations.
- Use sub-bottom surveys to determine the extent of soft sediment on riprap slopes and the extent of riprap keyways.
- Perform geotechnical testing on sediment cores for physical properties to assess, for example, material handling properties and sediment strength for capping as needed.
- Refine remedial technology assignments based on the investigations above.

Appropriate agencies and stakeholders will review remedial design documents. Costs for remedial design are incorporated into the design and permitting line item, which is assumed to be 5% of project construction costs (see Appendix E).

8.1.4 Monitoring

Monitoring is a key assessment technology for sediment remediation. Numerous guidance documents highlight the need for monitoring to verify achievement of project RAOs (EPA 1998, 2005; NRC 2007). For contaminated sediment projects, monitoring can be grouped into five categories (EPA 2005):

- **Pre-construction baseline monitoring –** EW-wide monitoring concurrent with remedial design studies, but separate in design and function
- **Construction monitoring –** Location-specific short-term monitoring during construction to verify performance of the operations
- **Confirmation sampling –** Location-specific performance monitoring immediately following active remediation prior to contractor demobilization
- **Operations and maintenance (O&M) monitoring –** Area- and location-specific monitoring to confirm that technologies are operating as intended (such as MNR)
- **Long-term monitoring –** EW-wide monitoring to confirm that the waterway is making progress toward or achieving the RAOs

The monitoring results from each category inform and direct adaptive management activities to verify long-term remedy implementation and achievement of RAOs. The approximate scope of monitoring for each alternative has been developed in Appendix G based on the remedial areas for each alternative. Each remediation type area was multiplied by sampling unit costs in Appendix G.

8.1.5 Adaptive Management

Adaptive management is the use of data collected during and after remediation to optimize remedial effectiveness. Adaptive management may be used to optimize remedial construction methods and to address remediated areas that may not perform as anticipated. The framework and criteria for adaptive management will be developed in remedial design. Relevant agencies are involved in reviewing adaptive management decisions. Some of the ways that adaptive management may affect the implementation of specific remedial technologies are discussed below.

In dredging and partial dredge and capping areas, data collected during construction monitoring may be used to more effectively employ BMPs while performing remediation to reduce short-term environmental impacts. Post-construction performance monitoring provides information on whether RALs were achieved, which could identify the need for managing dredge residuals. In capping areas, O&M monitoring could identify and assess cap stability and effectiveness and the need to modify the cap.

In MNR, ENR, and in situ treatment areas, O&M monitoring will be used to assess whether RALs have been successfully achieved over the required timeframe. Monitoring in these areas will be used to track the performance of natural recovery in the specific area being remediated and may inform the need for contingency actions.

The long-term monitoring program will include provisions for specific monitoring activities following a disruptive event such as an earthquake, to assess potential impacts and to develop appropriate response actions.

To account for potential contingency actions under the adaptive management framework, 15% of MNR, ENR, and in situ treatment areas are assumed to require additional remediation at $1 million per acre in open-water areas, and $4 million per acre under piers and low bridges. These costs are approximate equal to the capital cost for dredging these areas (i.e., base costs without additional costs for construction contingencies, design, project management, etc.).

8.1.6 Project Sequencing

The project should be sequenced so as to reduce the chance of recontamination from releases during dredging and from uncontrolled sources. For the purpose of estimating the construction timeframe for the action alternatives it was assumed that dredging would be phased before placement in all locations, and that placement operations (i.e., capping, ENR, and in situ treatment) at one end of the waterway could take place concurrently with dredging operations at the other end of the waterway. RMC was assumed to be placed after all other remedial activities are complete. During design, project sequencing may also consider other factors, such as dredging areas with higher concentrations prior to those with lower concentrations, to minimize the impact of releases from dredging in the later stages of the project.

In accordance with EPA guidance and prudent practice, remedial actions generally should not commence until appropriate source control measures have been implemented and their performance verified. Source control programs are ongoing in the EW and are not anticipated to affect the sequence of remediation in the waterway. In certain cases, source control may be the limiting factor in scheduling portions of the in-water cleanup. Timing of source control and remediation efforts upstream of the EW OU (e.g., in the LDW) may also be considered when scheduling remediation of the EW OU.

The EW is an active navigation channel with multiple container terminals that operate 24 hours per day and 7 days per week. Implementation of remediation may require sequencing to accommodate operational needs at the terminals and navigational needs of vessels coming and going from the waterway. In particular, the dredging production rates are assumed to incorporate the need for dredge operations to work around berthed and navigating vessels. In open-water areas, it is assumed that vessel traffic will not significantly impact the dredging rate for a single operation. All underpier areas, however, are adjacent to active berthing areas, and diving schedules are likely to be significantly impacted by waterway activities.

Tribal netfishing in the EW OU will also be considered in establishing project phasing and sequencing. The estimated construction window is shorter than the standard fish window to accommodate tribal netfishing activities in the EW OU; however, even within the specified construction window, tribal fishing may affect the movement of barges, equipment, and work locations.

8.2 Detailed Description of Alternatives

The remedial alternatives selected in Appendix L for detailed and comparative analysis in Sections 9 and 10 of the FS are: 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), 3E(7.5), and the No Action alternative. As noted above, Alternatives 1A(12) through 3E(7.5) are referred to as the "action alternatives."

The key variables used for developing the remedial alternatives are the remedial technologies (discussed in Section 7) and the RALs (discussed in Section 6), as described in the following sections.

8.2.1 Remedial Technologies

Representative remedial technologies retained following screening in Section 7 form the basis for the alternatives. These alternatives include both active remedial technologies (i.e., removal, capping [with partial removal as necessary], ENR-nav [with partial removal as necessary], ENR-sill, and in situ treatment), and passive remedial technologies (i.e., MNR, site-wide monitoring, and institutional controls). Section 7.7 describes the CMAs and the CMA-specific selection of remedial technologies based on the elevation constraints, sediment stability, and practicability.

The CMAs are grouped into "open-water," which are areas with relatively unrestricted access for remediation, and "limited access areas," which are areas that are difficult to access with typical remediation equipment, and include both the underpier areas and the low bridge areas of the Sill Reach (see Figure 7-1). The open-water remedial technologies are discussed in Section 8.2.1.1, and the limited access area remedial technologies are discussed in Section 8.2.1.2.

As discussed in the Screening Memo (Anchor QEA 2012a) and Section 7, removal forms the basis of all action alternatives due to elevation constraints for navigation and high forces from propwash in the Deep Main Body Reach and berthing areas of the waterway. Removal and partial removal are performed on between 60% to 70% of the site (and 80% to 99% of the remediation area) for all action alternatives.

8.2.1.1 Open-water Remedial Technologies

The open-water CMAs were combined into four groups (Navigation Channel and Berth Areas, Shallow Main Body, Nearshore, and West Seattle Bridge) based on similar structural, waterway use, habitat, and water depth conditions, which result in a different set of potentially applicable remedial technologies. Based on the retained remedial technologies within these groups of CMAs, three technology options are presented to form the basis of the remedial alternatives. The technology options are ordered from the smallest to the largest removal area (all technology options rely primarily on removal due to the navigation depth requirements in the EW). Table 8-1 presents the three open-water technology options (1 through 3) retained in the four open-water CMA groups.

8.2.1.2 Limited Access Area Remedial Technologies

The limited access areas include the underpier CMAs and the two low bridge CMAs in the Sill Reach. These CMAs were divided into two limited access CMA groups based on similar structural, waterway use, habitat, and water depth conditions. Limited access areas present particular challenges for remediation and, as such, have a wider range of technology options than open-water CMAs. Based on the retained remedial technologies within these CMA groups, four technology options, which are referred to as "limited access area technology options" for simplicity, are presented to form the basis of the remedial alternatives. Note that the non-sequential lettering of these options (e.g., no option D) is due to some options being screened out in Appendix L. Table 8-2 presents the four technology options for the two CMA groups.

8.2.2 Remedial Action Levels

RALs, the point-based concentrations above which sediment is remediated, were the second key variable in the alternative assembly. Table 6-1 and Section 6.2 present the RALs; alternatives with two different PCB RALs (12 and 7.5 mg/kg OC) were carried forward into Section 8 to provide a range of remediation footprints for the detailed analysis and comparison of alternatives. The two RAL sets used for remedial alternatives are shown in Table 8-3.

Table 8-1
Open-water Technology Options

Open-water Technology Option	Navigation Channel and Berth Areas (110 acres)	Shallow Main Body (22 acres)[a]	Nearshore (8 acres)[a]	West Seattle Bridge (2 acres)[a]
	CMAs: *– Federal Navigation Channel – South* *– Federal Navigation Channel – North* *– Deep Draft Berth Areas (T-18, T-30, T-25)* *– Slip 27 Channel* *– Slip 36/T-46 Offshore* *– T-25 Nearshore* *– T-30 Nearshore* *– Junction Reach* *– Communication Cable Crossing*	*CMAs:* *– Shallow Main Body – North and South* *– Former Pier 24 Piling Field*	*CMAs:* *– Mound Area/Slip 27 Shoreline* *– Coast Guard Nearshore*	*CMA:* *– Sill Reach – West Seattle Bridge*
1	• Removal • Partial Removal with ENR-nav • ENR-nav	• Removal • Partial Removal and Cap	• Partial Removal and Cap	• ENR-sill
2	• Removal	• Removal • Partial Removal and Cap	• Partial Removal and Cap	• ENR-sill
3	• Removal	• Removal	• Partial Removal and Cap	• Removal

Notes:
1. Open-water CMAs are shown in Figure 8-1.
2. Remedial technology assignment areas for these options are shown in the appropriate alternative figures (see Figures 8-2 through 8-9).
a. The area for the CMAs represents the total area of the CMAs in that group.
CMA – construction management area
ENR – enhanced natural recovery
T – terminal

Table 8-2
Limited Access Area Technology Options

Limited Access Area Technology Option	Underpier (15 acres)[a]	Sill Reach – Low Bridges (2 acres)[a]
	CMA: – *Underpier areas*	*CMAs:* – *Spokane Street Bridge* – *Railroad Bridge*
A	• MNR	• MNR (subtidal) • ENR-sill (intertidal)
B	• In situ treatment	• ENR-sill
C+	• Diver-assisted hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL[b] • In situ treatment elsewhere	• ENR-sill
E	• Diver-assisted hydraulic dredging followed by in situ treatment	• ENR-sill

Notes:
1. Limited access area CMAs are shown in Figure 8-1.
2. Remedial technology assignment areas for these options are shown in the appropriate alternative figures (see Figures 8-2 through 8-9).

a. The area for the CMAs represents the total area of the CMAs.
b. The underpier dredging-specific action level for the C+ alternatives was developed for PCBs and Hg because they are the primary contributors of risks to human health and the benthic community (see Section 7.8.2).

CMA – construction management areas
CSL – cleanup screening level
ENR – enhanced natural recovery
Hg – mercury
MNR – monitored natural recovery
PCB – polychlorinated biphenyl

Table 8-3
Remedial Action Levels for Technology Development

RAL Set Denotation	Total PCBs RAL	RAL for Other Chemicals	Area Remediated
(12)	12 mg/kg OC	See Table 6-1 (same for all alternatives)	121 of 157 acres
(7.5)	7.5 mg/kg OC		132 of 157 acres

Notes:
mg/kg – milligrams per kilogram
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level

8.2.3 Screening of Alternatives

Sixteen alternatives were selected for screening in coordination with EPA to capture the range of technology options and to support comparison of each of the varied parameters (i.e., RAL, open-water technology group, or limited access area technology group). Results of that screening are presented in Appendix L. Generally, alternatives that did not differentiate from other alternatives in effectiveness and implementability but had larger costs were screened out. The alternatives retained for the detailed and comparative analysis in Sections 9 and 10 are listed below, and shown in Tables 8-4 and 8-5 and Figures 8-2 through 8-10. As a reminder, RALs are the same in all alternatives except for total PCB, which vary as shown in Table 8-4.

Table 8-4
Retained Alternatives and Alternative Key

	Alternatives Key (General Description)		
Retained Alternatives	**Open-water**	**Restricted Access (underpier and low bridges)**	**PCBs RAL**
No Action 1A(12) 1B(12) 1C+(12) 2B(12) 2C+(12) 3B(12) 3C+(12) 2C+(7.5) 3E(7.5)	1 – Removal with capping and ENR where applicable 2 – Removal with capping where applicable 3 – Maximum removal to the extent practicable	A – MNR B – In situ treatment C+ – Diver assisted hydraulic dredging followed by in situ treatment for PCBs or Hg > CSL; In situ treatment elsewhere E – Diver-assisted hydraulic dredging followed by in situ treatment	(12) – 12 mg/kg OC (7.5) – 7.5 mg/kg OC

Notes:
CSL – cleanup screening level
ENR – enhanced natural recovery
Hg – mercury
mg/kg – milligrams per kilogram
MNR – monitored natural recovery
OC – organic carbon
PCB – polychlorinated biphenyl

Table 8-5
Remedial Technology Summary for Alternatives by CMA

	Open-water CMA Groups				Limited Access CMA Groups	
	Deep Main Body and Berth Areas (110 acres)	**Shallow Main Body (22 acres)**	**Nearshore (8 acres)**	**Sill Reach – West Seattle Bridge (2 acres)**	**Underpier (15 acres)**	**Sill Reach – Low Bridges (2 acres)**
Alternative	*CMAs:* *– Federal Navigation Channel – South* *– Federal Navigation Channel – North* *– Deep Draft Berth Areas (T 18, T-30, T-25)* *– Slip 27 Channel* *– Slip 36/T-46 Offshore* *– T-25 Nearshore* *– T-30 Nearshore* *– Junction Reach* *– Communication Cable Crossing*	*CMAs:* *– Shallow Main Body – North and South* *– Former Pier 24 Piling Field*	*CMAs:* *– Mound Area/Slip 27 Shoreline* *– Coast Guard Nearshore*	*CMA:* *– Sill Reach – West Seattle Bridge*	*CMA:* *– Underpier Areas*	*CMAs:* *– Sill Reach – Spokane Street Bridge* *– Sill Reach – Railroad Bridge*
No Action	No Action	No Action	No Action	No Action	No Action	No Action
1A(12)	Removal / Partial Removal and ENR-nav / ENR-nav	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	MNR	ENR-sill/MNR
1B(12)	Removal / Partial Removal and ENR-nav / ENR-nav	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	In situ Treatment	ENR-sill
1C+(12)	Removal / Partial Removal and ENR-nav / ENR-nav	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	Hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL / In situ treatment elsewhere	ENR-sill
2B(12)	Removal	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	In situ Treatment	ENR-sill
2C+(12)	Removal	Removal / Partial Removal and Cap	Partial Removal and Cap	ENR-sill	Hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL / In situ treatment elsewhere	ENR-sill
3B(12)	Removal	Removal	Partial Removal and Cap	Removal	In situ Treatment	ENR-sill
3C+(12)	Removal	Removal	Partial Removal and Cap	Removal	Hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL / In situ treatment elsewhere	ENR-sill
2C+(7.5)	Removal	Removal	Partial Removal and Cap	Removal	Hydraulic dredging ***followed by in situ treatment*** for PCBs or Hg > CSL / In situ treatment elsewhere	ENR-sill
3E(7.5)	Removal	Removal	Partial Removal and Cap	Removal	Hydraulic dredging followed by in situ treatment	ENR-sill

Notes:
1. Acres for each CMA represent the entire CMA footprint with sediment including areas below RALs that are identified as not requiring remediation. Areas are rounded to the closest acre.
2. See Figure 7-1 for a map of CMA areas.
CMA – Construction Management Area
ENR – enhanced natural recovery
MNR – monitored natural recovery
RAL – remedial action level
T – Terminal

Taken together, the alternatives present a range of remedial options applicable in the EW OU, based on the CMA-specific screening of remedial technologies in Table 7-4. This range in alternatives provides a range in characteristics (areas, volumes, costs, effectiveness, etc.) so that the alternatives can be compared in subsequent sections of this FS. The technology assignment areas, volumes, and costs for each alternative are described in the following sections.

8.2.4 No Action

This alternative assumes that no remedial actions will occur (Figure 8-1). The No Action alternative is required as part of CERCLA FS evaluation process. It is considered a natural recovery alternative,[91] and the only activity for this alternative is site-wide monitoring.

Note that the No Action alternative includes past remedial actions that have been performed in the water such as the non-time critical removal action (NTCRA) performed in 2005; however, costs for these actions are not included in the cost estimate for the No Action alternative. The FS baseline dataset represents post-NTCRA conditions (i.e., data from dredged areas has been removed as appropriate).

8.2.5 Alternative 1A(12)

Alternative 1A(12) is based on open-water option 1 (Table 8-1): removal with capping and ENR-nav where applicable; limited access option A (Table 8-2): MNR; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-2. Like all the action alternatives, Alternative 1A(12) is removal focused, with removal over 80% of the remediation area (62% of the EW). In comparison with the other action alternatives, Alternative 1A(12) relies the most on natural recovery by using MNR (in limited access areas) and ENR (in the Deep Main Body and the Sill Reach). Alternative 1A(12) also employs capping where practicable (in the Shallow Main Body).

[91] "Natural recovery" is distinct from "monitored natural recovery (MNR)" in this context. MNR includes targeted location-specific monitoring, target concentrations, and contingency actions if target concentrations are not achieved. Natural recovery includes site-wide monitoring only, with no target concentrations or contingency actions if target concentrations are not met.

Alternative 1A(12) includes the following combination of remedial technologies:

- **Open-water Option 1 (Table 8-1):**
  - **Navigation Channel and Berth Area:** Removal, ENR-nav, or partial removal and ENR-nav. The Communication Cable Crossing includes removal to the extent practicable and backfill instead of removal to RAL exceedances to protect the structure.
  - **Shallow Main Body Reach:** Removal or partial removal and capping.
  - **Nearshore:** Partial removal and cap.
  - **West Seattle Bridge**: ENR-sill.
- **Limited Access Option A (Table 8-2):**
  - **Underpier areas**: MNR.
  - **Sill Reach – Low Bridges**: ENR-sill in intertidal areas and MNR in subtidal areas.

Table 8-6 shows the total remedial areas and the estimated volumes, costs, and construction timeframes for the alternatives. Alternative 1A(12) includes 97 acres of removal (including 77 acres of removal, 13 acres of partial removal and capping, 7 acres of partial removal and ENR-nav), 2 acres of ENR-sill, 9 acres of ENR-nav, and 13 acres of MNR (under piers and low bridges). The total removal volume is estimated at 810,000 cy and the total placement volume (capping, ENR, RMC layer, and backfill) is 290,000 cy. The alternative will take approximately 9 years to construct (approximately eight seasons of dredging), at a cost of approximately $256 million. The implementation of construction, institutional controls, monitoring, and adaptive management are described in Sections 7 and 8.1.

8.2.6 Alternative 1B(12)

Alternative 1B(12) is based on open-water option 1 (Table 8-1): removal with capping and ENR-nav where applicable; limited access option B (Table 8-2): in situ treatment; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-3.

Table 8-6
Areas, Volumes, and Costs for Alternatives

	Area (acres)																	Volume (cubic yards)			
	Open-water and Under Low Bridges										Underpier										
Alternative	Removal	Removal to the Extent Practicable and Backfill (Communication Cable Crossing Area)	Removal and Backfill to Existing Contours	Partial Removal and Capping	Partial Removal and ENR-nav	ENR-nav	ENR-sill	MNR	Interior Unremediated Area[a]	Exterior Unremediated Area	Hydraulic Dredging Followed by in situ Treatment	In situ Treatment	MNR	Underpier Unremediated	Total Remediated Area	No Action Area	Total Area[b]	Total Removal Volume[c]	Total Placement Volume (capping, ENR, in situ treatment, RMC)	Total Cost[d]	Construction Timeframe (years)
No Action	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**157**	**157**	0	0	$950,000	0
1A(12)	73	3	1	13	7	9	2	1	19	15	0	0	12	2	**121**	36	**157**	810,000	290,000	$256,000,000	9
1B(12)	73	3	1	13	7	9	3	0	19	15	0	12	0	2	**121**	36	**157**	810,000	290,000	$264,000,000	9
1C+(12)	73	3	1	13	7	9	3	0	19	15	2	10	0	2	**121**	36	**157**	820,000	290,000	$277,000,000	9
2B(12)	88	5	1	13	0	0	3	0	19	15	0	12	0	2	**121**	36	**157**	900,000	280,000	$284,000,000	10
2C+(12)	88	5	1	13	0	0	3	0	19	15	2	10	0	2	**121**	36	**157**	910,000	280,000	$297,000,000	10
3B(12)	92	5	3	7	0	0	1	0	19	15	0	12	0	2	**121**	36	**157**	960,000	270,000	$298,000,000	10
3C+(12)	92	5	3	7	0	0	1	0	19	15	2	10	0	2	**121**	36	**157**	960,000	270,000	$310,000,000	10
2C+(7.5)	98	5	1	13	0	0	3	0	15	8	2	11	0	2	**132**	25	**157**	1,010,000	290,000	$326,000,000	11
3E(7.5)	102	5	4	7	0	0	1	0	15	8	13	0	0	2	**132**	25	**157**	1,080,000	270,000	$411,000,000	13

Notes:
a. Interior unremediated areas are sediment areas with no RAL exceedances, but which are surrounded by areas to be remediated. For FS purposes, an RMC layer is assumed to be placed in these areas (see Appendix F for more details).
b. Area does not include locations without sediment (i.e., 19 acres of uncovered riprap) in the Underpier, T-25 Nearshore, and T-30 Nearshore Construction Management Areas.
c. Removal volume is based on the assumptions in Appendix F and include the neatline dredging volume multiplied by a design factor of 1.5, except for underpier areas (which is based on the neatline volume without a design factor because sediment is underlain by riprap).
d. Costs are based on assumptions in Appendix E.
All values are rounded for presentation. Apparent discrepancies in totals are only due to rounding.
ENR-nav – enhanced natural recovery applied in the navigation channel and deep-draft berthing areas
ENR-sill – enhanced natural recovery used in the Sill Reach
FS – Feasibility Study
MNR – monitored natural recovery
RAL – remedial action level
RMC – residuals management cover

Like Alternative 1A(12), Alternative 1B(12) is removal focused, with removal over 80% of the remediation area (62% of the EW). Alternative 1B(12) is the same as Alternative 1A(12), except that it replaces MNR with in situ treatment as a remedial technology in underpier areas.

Alternative 1B(12) includes the following combination of remedial technologies:

- **Open-water Option 1 (Table 8-1):** As described for Alternative 1A(12), above.
- **Limited Access Option B (Table 8-2):**
  - **Underpier areas:** In situ treatment.
  - **Sill Reach – Low Bridges:** ENR-sill

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 1B(12) includes 97 acres of removal (77 acres of removal, 13 acres of partial removal and capping, 7 acres of partial removal and ENR-nav), 3 acres of ENR-sill, 9 acres of ENR-nav, and 12 acres of in situ treatment. The total removal volume is estimated at 810,000 cy, and the total placement volume (capping, ENR, RMC layer, and backfill) is 290,000 cy. The alternative has the same construction timeframe (9 years) as Alternative 1A(12), because in situ treatment would occur concurrently with removal operations. Alternative 1B(12) is estimated to cost $264 million. The implementation of construction, institutional controls, monitoring, and adaptive management are described in Sections 7.2 and 8.1.

8.2.7 Alternative 1C+(12)

Alternative 1C+(12) is based on open-water option 1 (Table 8-1): removal with capping and ENR-nav where applicable; limited access area option C+ (Table 8-2): removal followed by in situ treatment for areas with PCBs or mercury greater than the CSL and in situ treatment elsewhere when exceeds RALs; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-4.

Alternative 1C+(12) is removal focused, with removal over 82% of the remediation area (63% of the EW). Alternative 1C+(12) is the same as Alternative 1A(12), except that it replaces

MNR with in situ treatment and hydraulic dredging followed by in situ treatment as the remedial technologies in underpier areas.

Alternative 1C+(12) includes the following combination of remedial technologies:

- **Open-water Option 1 (Table 8-1):** As described for Alternative 1A(12), above.
- **Limited Access Option C+ (Table 8-2):**
  - **Underpier areas:** Limited removal using hydraulic dredging followed by in situ treatment was selected for areas with PCBs or mercury concentrations exceeding the CSL. In situ treatment (without being preceded by hydraulic dredging) would be applied in other areas exceeding the RALs.
  - **Sill Reach – Low Bridges:** ENR-sill (same as Alternative 1B(12)).

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 1C+(12) includes 99 acres of removal (77 acres of removal, 13 acres of partial removal and capping, 7 acres of partial removal and ENR-nav, 2 acres of hydraulic dredging followed by in situ treatment), 3 acres of ENR-sill, 9 acres of ENR-nav, and 10 acres of in situ treatment. The total removal volume is estimated at 820,000 cy, and the total placement volume (capping, ENR, RMC layer, and backfill) is 290,000 cy. The alternative has the same construction timeframe (9 years) as Alternative 1B(12), because diver-assisted hydraulic dredging would occur concurrently with open-water removal operations. Alternative 1C+(12) is estimated to cost $277 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.8 Alternative 2B(12)

Alternative 2B(12) is based on open-water option 2 (Table 8-1): removal with capping where applicable; limited access option B (Table 8-2): in situ treatment; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-5.

Alternative 2B(12) is removal focused, with removal over 88% of the remediation area (68% of the EW). Alternative 2B(12) is identical to Alternative 1B(12), except that ENR-nav and partial dredging and ENR-nav are substituted by removal of sediment exceeding RALs. Like Alternative 1B(12), Alternative 2B(12) includes partial dredging and capping where practicable in the Shallow Main Body. Alternative 2B(12) includes the following combination of remedial technologies:

- **Open-water Option 2 (Table 8-1):**
  - **Navigation Channel and Berth Area:** Removal. The Communication Cable Crossing includes removal to the extent practicable and backfill instead of removal to RAL exceedances to protect the structure.
  - **Shallow Main Body Reach:** Removal or partial removal and capping (same as described for Alternative 1A(12)).
  - **Nearshore:** Partial removal and cap (same as described for Alternative 1A(12)).
  - **West Seattle Bridge:** ENR-sill (same as described for Alternative 1A(12)).
- **Limited Access Option B (Table 8-2):** As described for Alternative 1B(12), above.

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 2B(12) includes 106 acres of removal (93 acres of removal and 13 acres of partial removal and capping), 12 acres of in situ treatment, and 3 acres of ENR-sill. The total removal volume is estimated at 900,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 280,000 cy. The alternative will take approximately 10 years to construct, at a cost of approximately $284 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.9 Alternative 2C+(12)

Alternative 2C+(12) is based on open-water option 2 (Table 8-1): removal with capping where applicable; limited access option C+ (Table 8-2): removal followed by in situ treatment for areas with PCBs or mercury greater than the CSL and in situ treatment elsewhere; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-6.

Alternative 2C+(12) is removal focused, with removal over 90% of the remediation area (69% of the EW). Alternative 2C+(12) is the same as Alternative 2B(12), except that it includes limited removal using diver-assisted hydraulic dredging (for PCBs or mercury greater than the CSL) followed by in situ treatment as remedial technologies in underpier areas. Alternative 2C+(12) includes the following combination of remedial technologies:

- **Open-water Option 2 (Table 8-1):** As described for Alternative 2A(12), above.
- **Limited Access Option C+ (Table 8-2):** As described for Alternative 1C+(12), above.

Table 8-6 shows the total remedial areas, volumes, costs, and construction timeframes for the alternative. Alternative 2C+(12) includes 108 acres of removal (93 acres of removal, 13 acres of partial removal and capping, and 2 acres of hydraulic dredging followed by in situ treatment), 3 acres of ENR-sill, and 10 acres of in situ treatment. The total removal volume is estimated at 910,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 280,000 cy. The alternative has the same construction timeframe (10 years) as Alternative 2B(12), because diver-assisted hydraulic dredging would occur concurrently with open-water removal operations. Alternative 2C+(12) is estimated to cost $297 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.10 Alternative 3B(12)

Alternative 3B(12) is based on open-water option 3 (Table 8-1): maximum removal to the extent practicable in open-water areas; limited access option B (Table 8-2): in situ treatment; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-7.

Alternative 3B(12) is removal focused, with removal over 88% of the remediation area (69% of the EW). Alternative 3B(12) is identical to Alternative 2B(12), but uses removal where practicable in the open-water areas (i.e., removal in the Shallow Main Body CMAs and under the West Seattle Bridge). Alternative 3B(12) includes the following combination of remedial technologies:

- **Open-water Option 3 (Table 8-1):**
  - **Navigation Channel and Berth Area:** Removal. The Communication Cable Crossing includes removal to the extent practicable and backfill instead of removal to RAL exceedances to protect the structure (same as described for Alternative 2B(12)).

   - **Shallow Main Body Reach:** Removal.
   - **Nearshore:** Partial removal and cap (same as described for Alternative 1A(12)).
   - **West Seattle Bridge:** Removal.
- **Limited Access Option B (Table 8-2):** As described for Alternative 1B(12), above.

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 3B(12) includes 108 acres of removal (101 acres of removal, 7 acres of partial removal and capping), 12 acres of in situ treatment, and 1 acre of ENR-sill. The total removal volume is estimated at 960,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 270,000 cy. The alternative will take approximately 10 years to construct, at a cost of approximately $298 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.11 Alternative 3C+(12)

Alternative 3C+(12) is based on open-water option 3 (Table 8-1): maximum removal to the extent practicable in open-water areas; limited access option C+ (Table 8-2): removal followed by in situ treatment for areas with PCBs or mercury greater than the CSL and in situ treatment elsewhere exceeding RALs; and the RAL set including 12 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-8.

Alternative 3C+(12) is removal focused, with removal over 90% of the remediation area (70% of the EW). Alternative 3C+(12) is the same as 2C+(12) but uses removal where practicable in the open-water areas (i.e., removal in the Shallow Main Body CMAs). Alternative 3C+(12) includes the following combination of remedial technologies:

- **Open-water Option 3 (Table 8-1):** As described for Alternative 3B(12), above.
- **Limited Access Option C+ (Table 8-2):** As described for Alternative 1C+(12), above.

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 3C+(12) includes 110 acres of removal (101 acres of removal, 7 acres of partial removal and capping, 2 acres of hydraulic dredging followed by in situ treatment), 1 acre of ENR-sill, and 10 acres of in situ treatment. The total removal volume is estimated at 960,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 270,000 cy. The alternative will take approximately 10 years to construct, at a cost of approximately $310 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.12 Alternative 2C+(7.5)

Alternative 2C+(7.5) is based on open-water option 2 (Table 8-1): removal with capping where applicable; limited access option C+ (Table 8-2): removal followed by in situ treatment in areas with PCBs or mercury greater than the CSL and in situ treatment elsewhere above RALs; and the RAL set including 7.5 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-9.

Alternative 2C+(7.5) is removal focused, with removal over 90% of the remediation area (75% of the EW). Is identical to Alternative 2C+(12), except for a larger remediation area due to a lower RAL for PCBs. Alternative 2C+(7.5) includes the following combination of remedial technologies:

- **Open-water Option 2 (Table 8-1):** Same as described for Alternative 2B(12), above, but with a larger remediation area due to the lower RAL.
- **Limited Access Option C+ (Table 8-2):** Same as described for Alternative 1C+(12), above, but with a larger remediation area due to the lower RAL.

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 2C+(7.5) includes 118 acres of removal (103 acres of dredging, 13 acres of partial removal and capping, 2 acres of hydraulic dredging followed by in situ treatment), 3 acres of ENR-sill, and 11 acres of in situ treatment. The total removal volume is estimated at 1,010,000 cy, and the total placement volume (capping, in situ treatment, ENR, RMC layer, and backfill) is 290,000 cy. The alternative will take approximately 11 years to construct, at a cost of approximately $326 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1.

8.2.13 Alternative 3E(7.5)

Alternative 3E(7.5) is based on open-water option 3 (Table 8-1): maximum removal to extent practicable; limited access option E (Table 8-2): removal followed by in situ treatment in all areas exceeding RALs; and the RAL set including 7.5 mg/kg OC for PCBs (Table 8-3). The detailed remediation areas and technology assignments are presented in Table 8-5 and Figure 8-10.

Alternative 3E(7.5) can be considered the overall most aggressive removal-focused alternative with maximum removal in the open-water areas due to a PCB RAL of 7.5 mg/kg OC, combined with hydraulic dredging followed by in situ treatment in underpier areas. Alternative 3E(7.5) includes the following combination of remedial technologies:

- **Open-water Option 3 (Table 8-1):** Same as described for Alternative 3C+(12), above, but with a larger remediation area due to the lower RAL.
- **Limited Access Option E (Table 8-2):**
  - **Underpier areas:** Removal using hydraulic dredging followed by in situ treatment.
  - **Sill Reach – Low Bridges:** ENR-sill (same as Alternative 1B(12)).

Table 8-6 shows the total remedial areas and estimated volumes, costs, and construction timeframes for the alternative. Alternative 3E(7.5) includes 131 acres of removal (111 acres of removal, 7 acres of partial removal and capping and 13 acres of hydraulic dredging followed by in situ treatment) and 1 acre of ENR-sill, The total removal volume is estimated at 1,080,000 cy, and the total placement volume (capping, ENR, RMC layer, and backfill) is 270,000 cy. The alternative will take approximately 13 years to construct, at a cost of approximately $411 million. The implementation of construction, institutional controls, monitoring, and adaptive management would be as described in Sections 7.2 and 8.1. Additional costs and construction timeframes for this alternative are entirely due to additional underpier footprint for diver-assisted hydraulic dredging.

8.3 Uncertainties

Sufficient data collection and analyses have been completed to develop and evaluate the alternatives for the FS. Overall, the alternatives are sufficiently defined to allow a detailed evaluation against the CERCLA criteria (Section 9), to perform a comparative analysis in accordance with CERCLA criteria (Section 10), and to support remedial decision-making. However, inherent in the conceptual nature of the FS process, key uncertainties remain regarding certain assumptions made in development of the alternatives. These uncertainties are further discussed below and include, but are not limited to, the following:

- Adequacy and timing of source control
- Volume and cost estimates
- Remedial technology assignments and expected performance
- Future land and waterway uses

8.3.1 Adequacy and Timing of Source Control

Remedial actions must be carefully coordinated with source control work, and generally should not commence until appropriate source control measures have been implemented and their performance verified. In certain cases, source control may be the limiting factor in scheduling in-water cleanup. Source control programs are ongoing in and upstream of the EW.

The construction timeframes and cost estimates assume that source control[92] will be sufficient prior to remediation; however, the timing and costs of remediation will be modified as more information is collected and integrated into remediation of the site.

8.3.2 Volume and Cost Estimates

Remedial design sampling will refine the estimated extent of contaminated sediment and confirm or modify the technology assignments identified in the FS. The assumptions used to define the remedial areas and volumes set forth in this section are reasonable and appropriate for an FS-level alternatives development and comparative process.

Likewise, the cost estimate was developed using pertinent guidance and costs from recent project experience. Although these represent the best-estimate of future project costs, many factors have an impact on project costs. Some of these factors are intrinsic to the site, such as areas and volumes requiring remediation and other site conditions. Other factors are extrinsic to the site, such as general economic conditions like inflation, the cost of

[92] Cost for source control actions are not included in the remedial alternative costs.

construction, transportation, and disposal. Per FS guidance, the cost estimate is considered accurate to +50%, -30%.

8.3.3 Remedial Technologies Assignments and Expected Performance

The alternatives have been assembled using a set of assumptions about the applicability and effectiveness of remedial technologies (Section 7). Some of these are straightforward (e.g., the assumption that capping is not applicable in most areas of the Deep Main Body Reach of the navigation channel due to anticipated vertical clearance requirements for vessel operations and future maintenance dredging and the vertical extent of contamination); other criteria are based on general assumptions that require confirmation during remedial design (e.g., cap armoring necessary for a given location). In total, these assessments could result in refinements to the technologies assignments during remedial design.

The FS recognizes that new technologies should not be discounted for consideration in the cleanup of the EW OU. For example, advances in in situ treatment and capping amendments may have the potential to improve cleanup and should be considered at the remedial design stage.

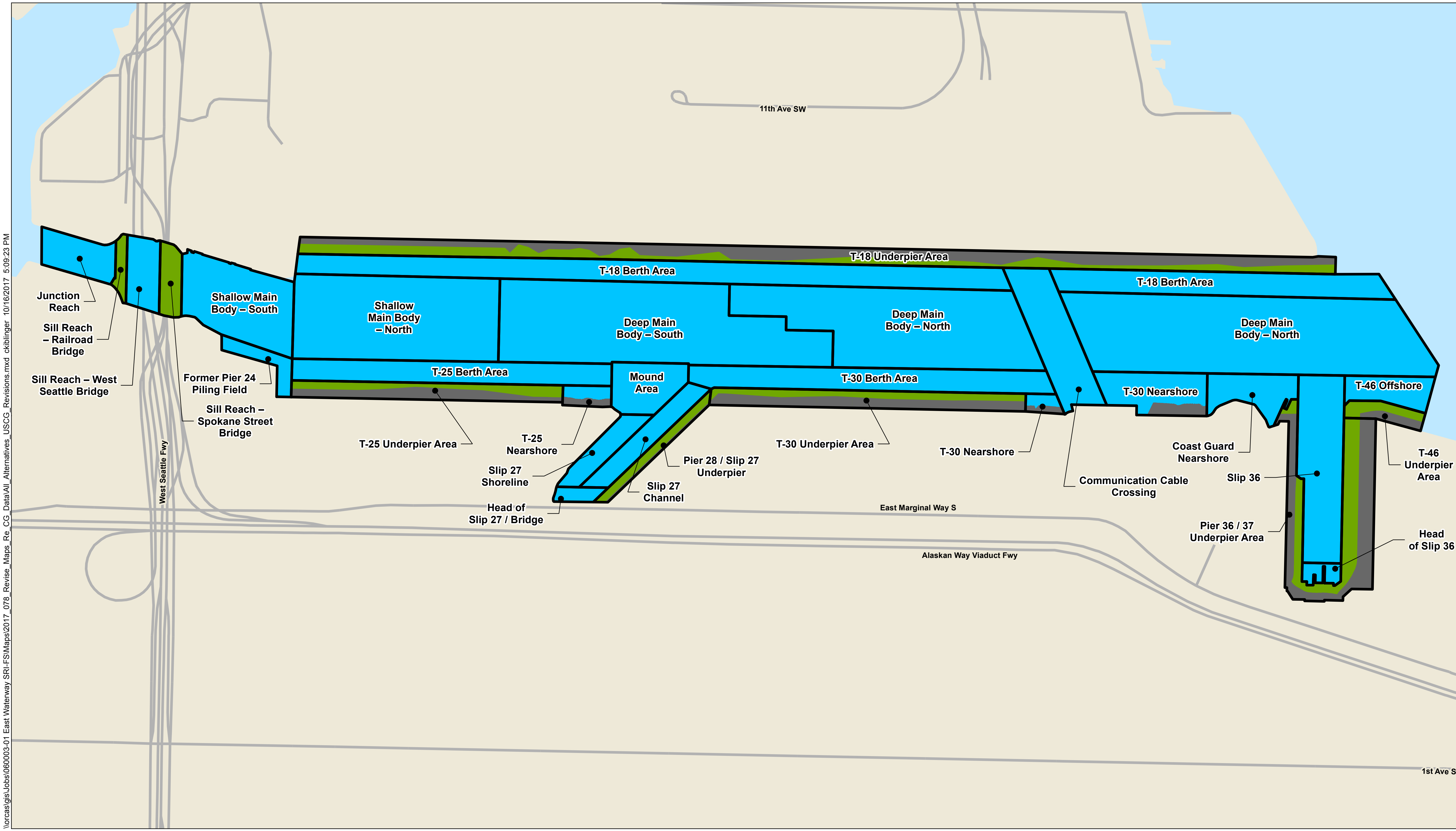
8.3.4 Future Land and Waterway Uses

The EW OU is an active port area and is intended to remain so. The waterway is expected to continue to be used by Muckleshoot and Suquamish Tribes for fishing and harvesting activities. Land bordering it is zoned for industrial and manufacturing uses. Two local jurisdictions have regulatory authority in the area near the EW: the City of Seattle and King County. These jurisdictions, along with the Port, have established planning priorities and goals for the EW that are described in the following planning documents:

- City of Seattle Comprehensive Plan 2012, available from: http://www.seattle.gov/DPD/Planning/Seattle_s_Comprehensive_Plan/Overview/
- City of Seattle Shoreline Master Program Updates 2012, available from: http://www.seattle.gov/dpd/Planning/ShorelineMasterProgramUpdate/Overview/
- King County Comprehensive Plan 2012, available from: http://www.kingcounty.gov/depts/executive/performance-strategy-budget/regional-planning/king-county-comprehensive-plan/2012Adopted.aspx

- King County Shoreline Master Program Update 2010, available from: http://www.kingcounty.gov/environment/waterandland/shorelines/program-update.aspx

As discussed in Section 2.9.2, USACE completed a draft SHNIP Feasibility Report and Environmental Assessment in August 2016 (USACE 2016) evaluating several alternatives for deepening and widening the federal navigation channel in the EW. No decision has been made to proceed with the recommended navigation improvement project, as implementation depends on approval and funding by the federal government and other parties. Therefore, the FS remedial alternatives are based on the current conditions and uses of the waterway. However, all of the EW remedial alternatives are compatible with the future implementation of the potential navigation improvement project, and the navigation improvement would not reduce the environmental protectiveness of the remedy in the EW.



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CMA Boundaries
Limited Access (Underpier and Low Bridge)
Open Water
Riprap (No Action)

0 500 1,000
Scale in Feet

Figure 8-1
Construction Management Area Groups
Feasibility Study
East Waterway Study Area

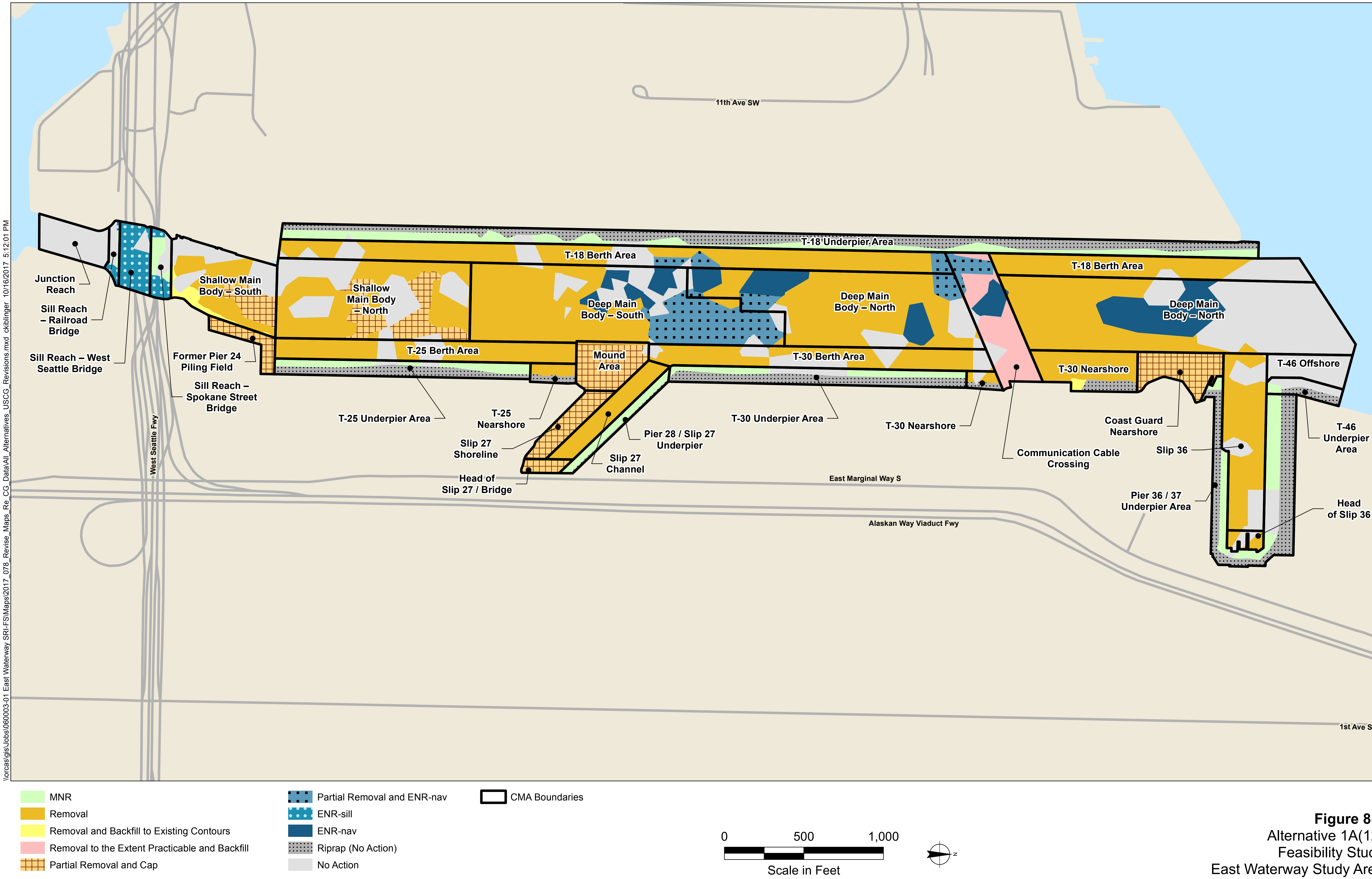

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Figure 8-2
Alternative 1A(12)
Feasibility Study
East Waterway Study Area

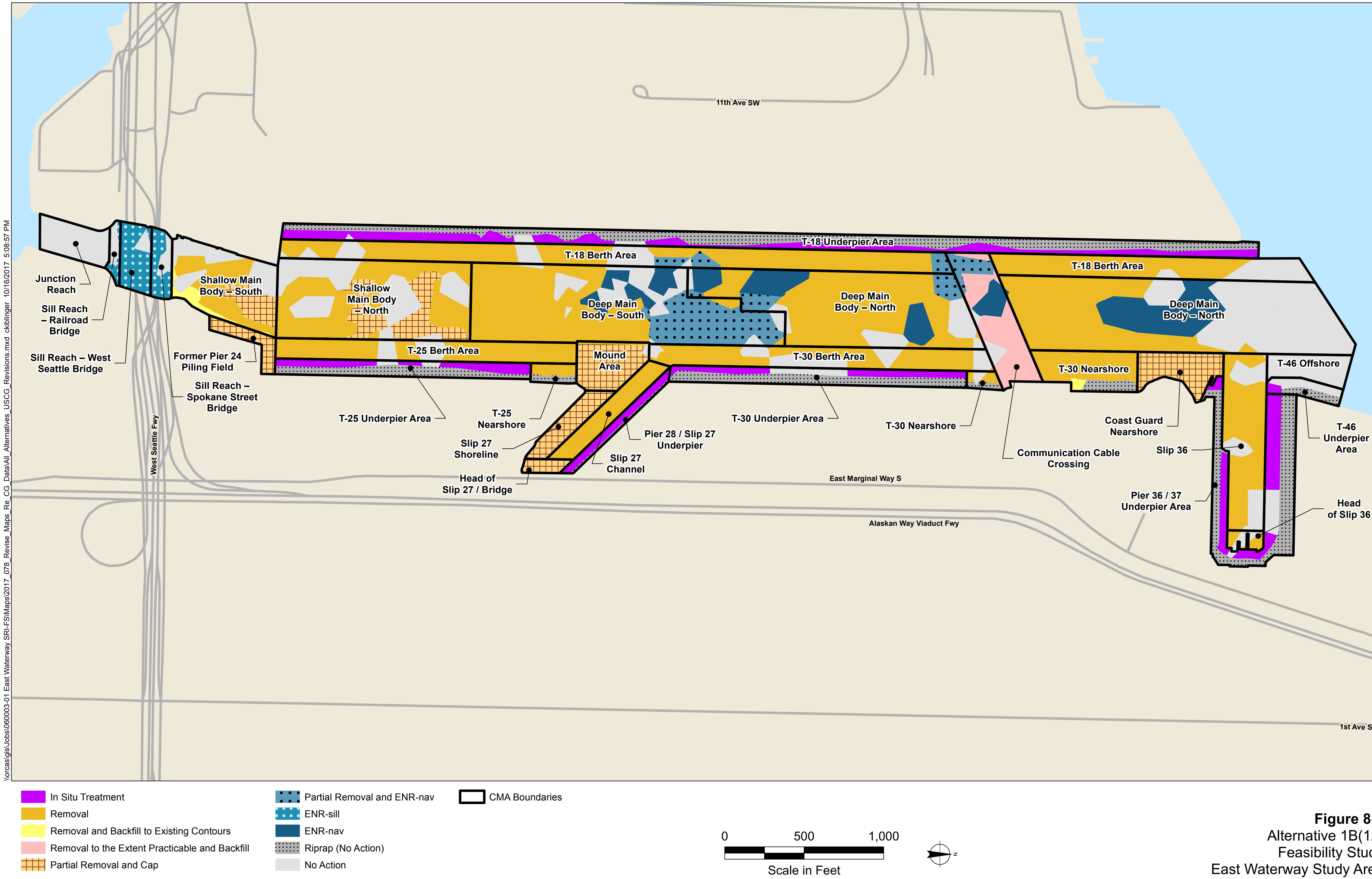
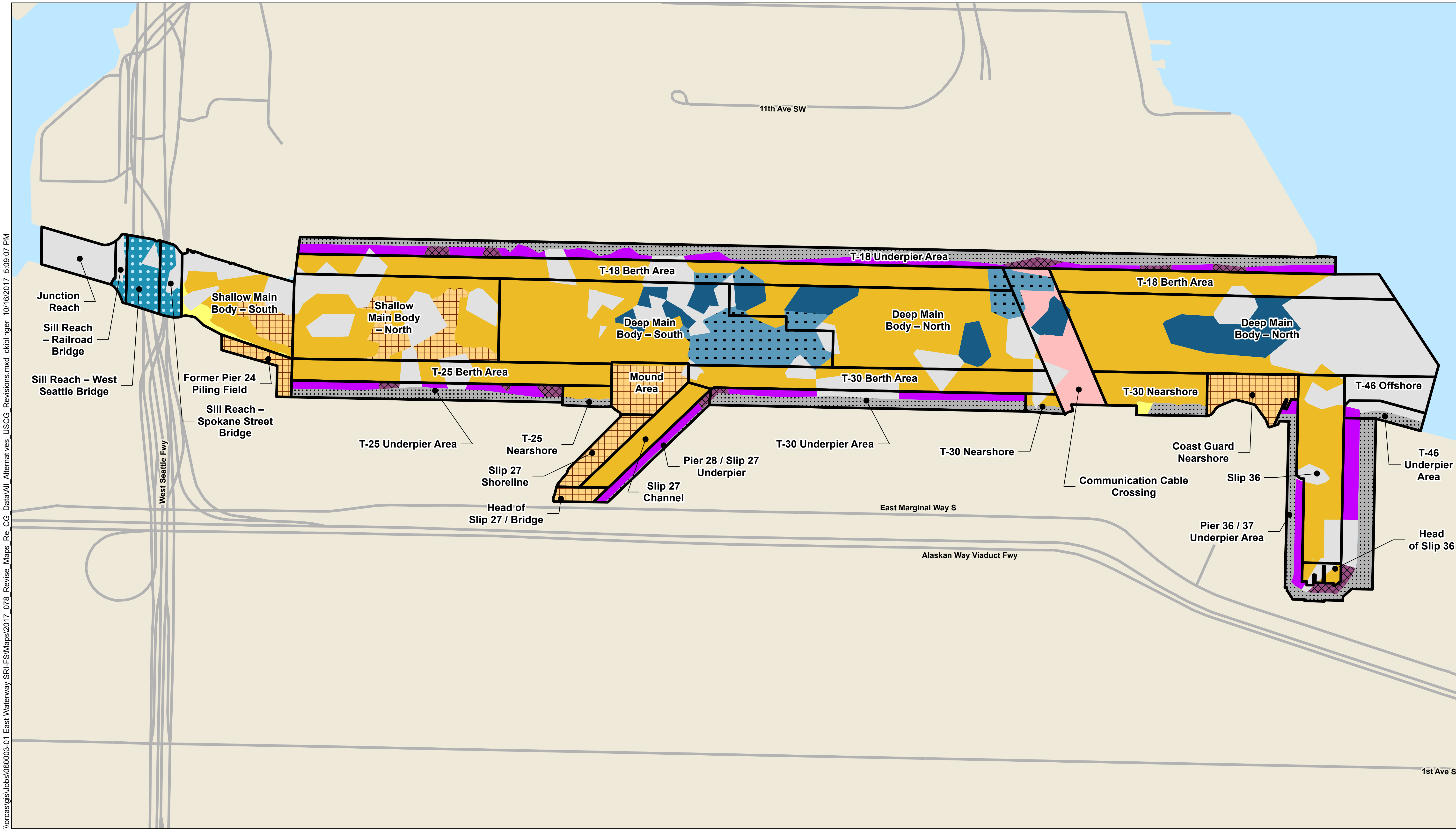


Figure 8-3
Alternative 1B(12)
Feasibility Study
East Waterway Study Area



Hydraulic Dredging Followed by In Situ Treatment
In Situ Treatment
Removal
Removal and Backfill to Existing Contours
Removal to the Extent Practicable and Backfill
Partial Removal and Cap
Partial Removal and ENR-nav
ENR-sill
ENR-nav
Riprap (No Action)
No Action
CMA Boundaries

0 500 1,000
Scale in Feet

Figure 8-4
Alternative 1C+(12)
Feasibility Study
East Waterway Study Area

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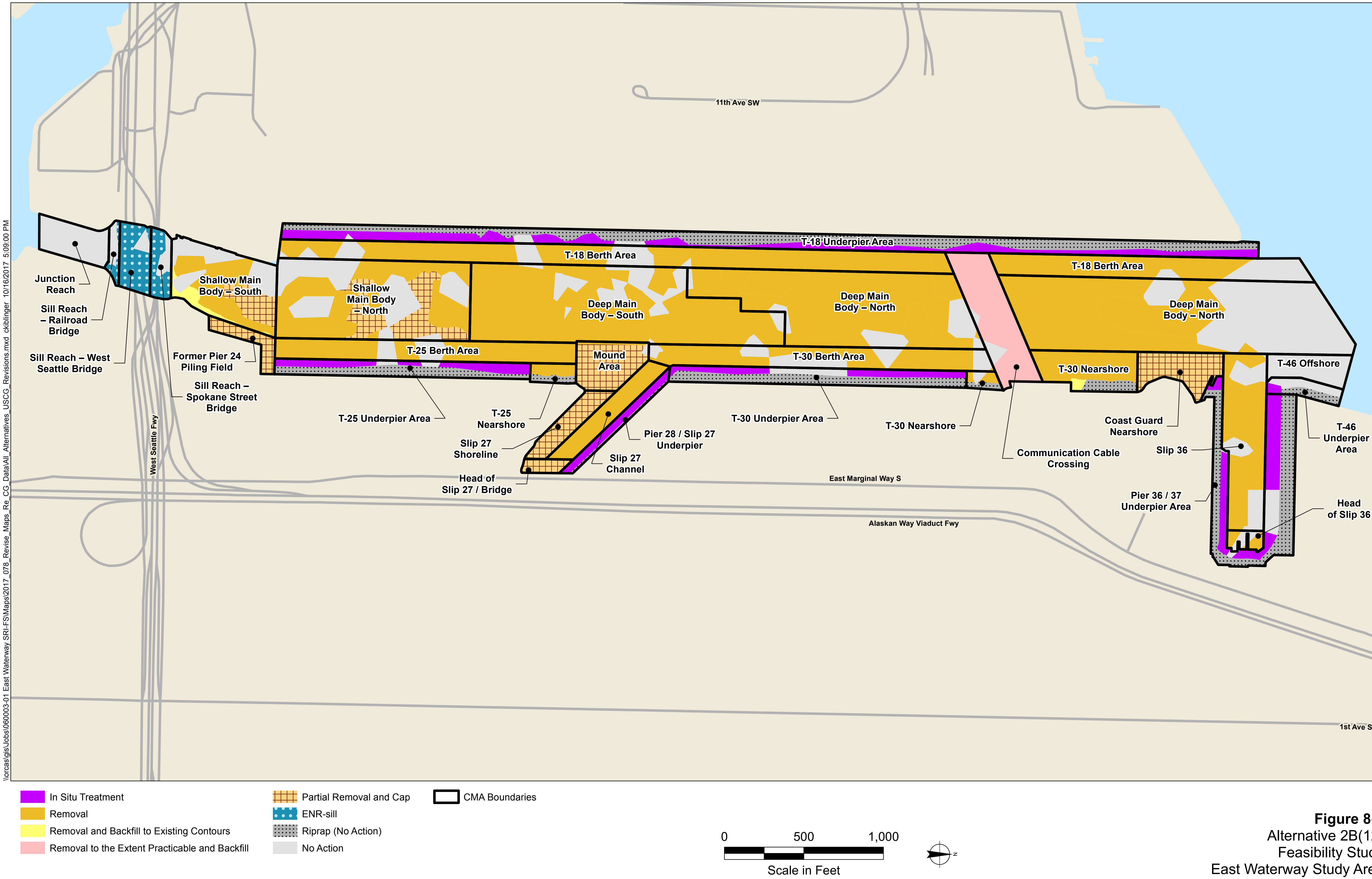
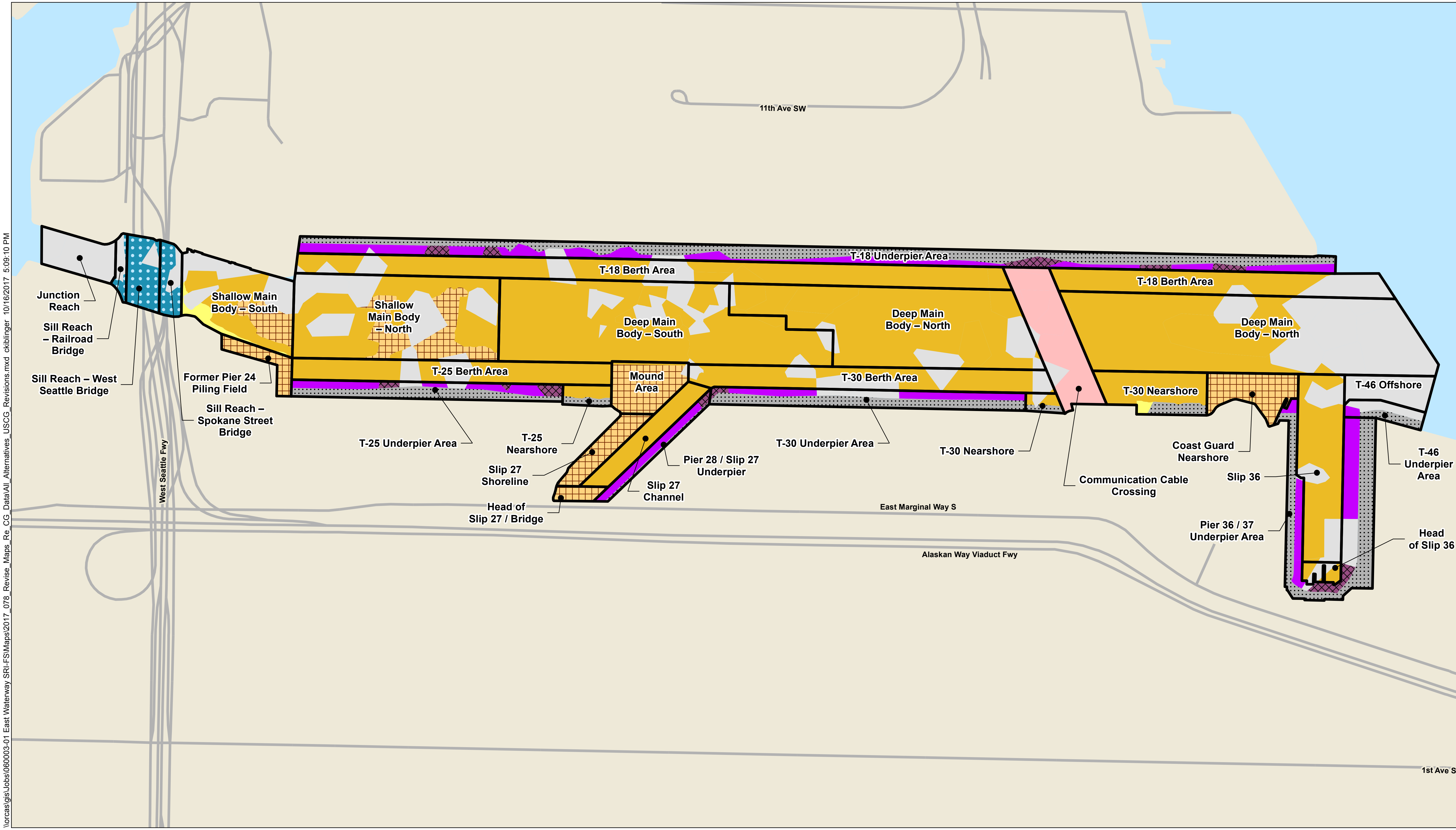


Figure 8-5
Alternative 2B(12)
Feasibility Study
East Waterway Study Area



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Hydraulic Dredging Followed by In Situ Treatment
In Situ Treatment
Removal
Removal and Backfill to Existing Contours
Removal to the Extent Practicable and Backfill
Partial Removal and Cap
ENR-sill
Riprap (No Action)
No Action
CMA Boundaries

0 500 1,000
Scale in Feet

Figure 8-6
Alternative 2C+(12)
Feasibility Study
East Waterway Study Area

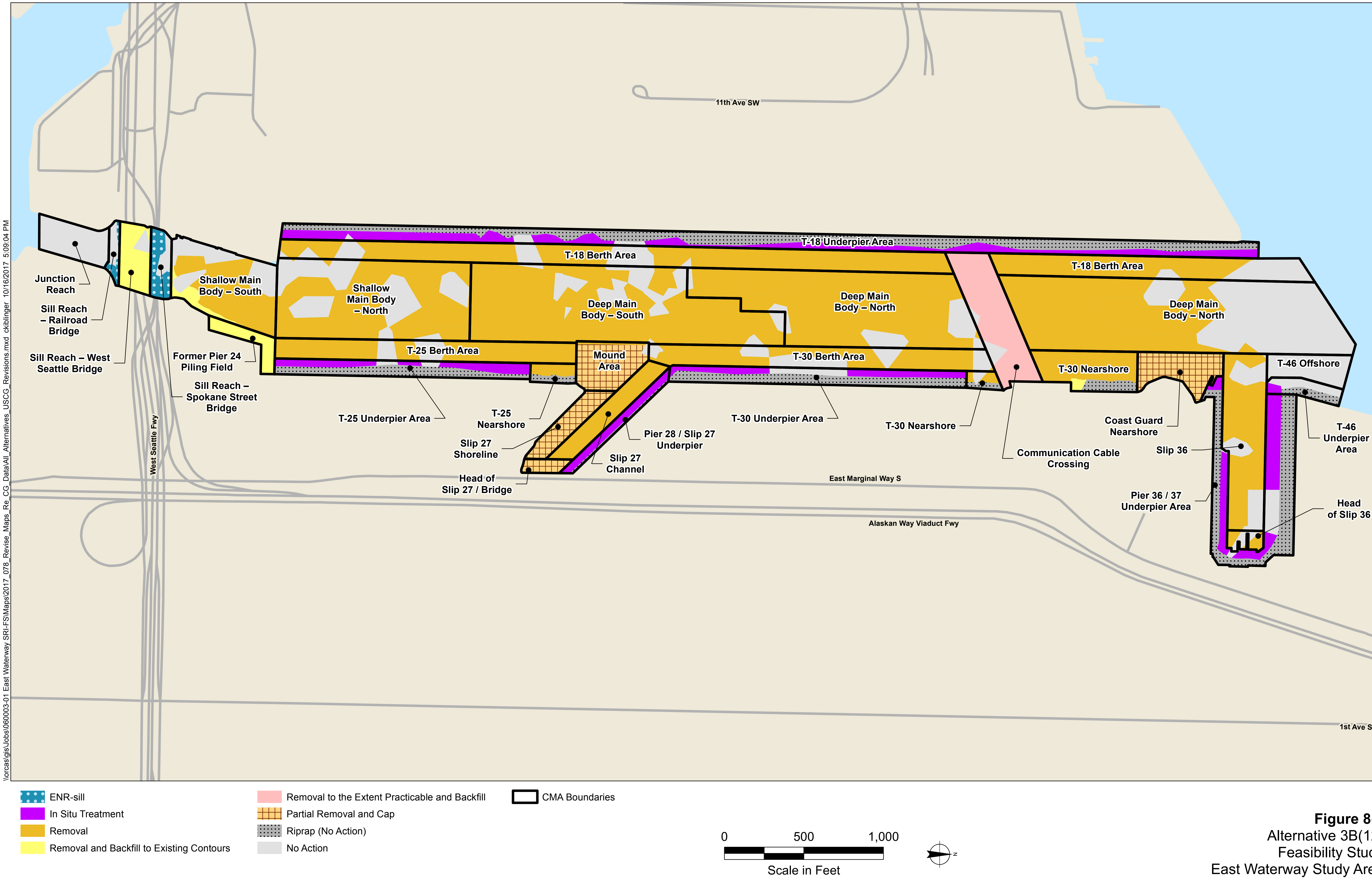

Figure 8-7
Alternative 3B(12)
Feasibility Study
East Waterway Study Area

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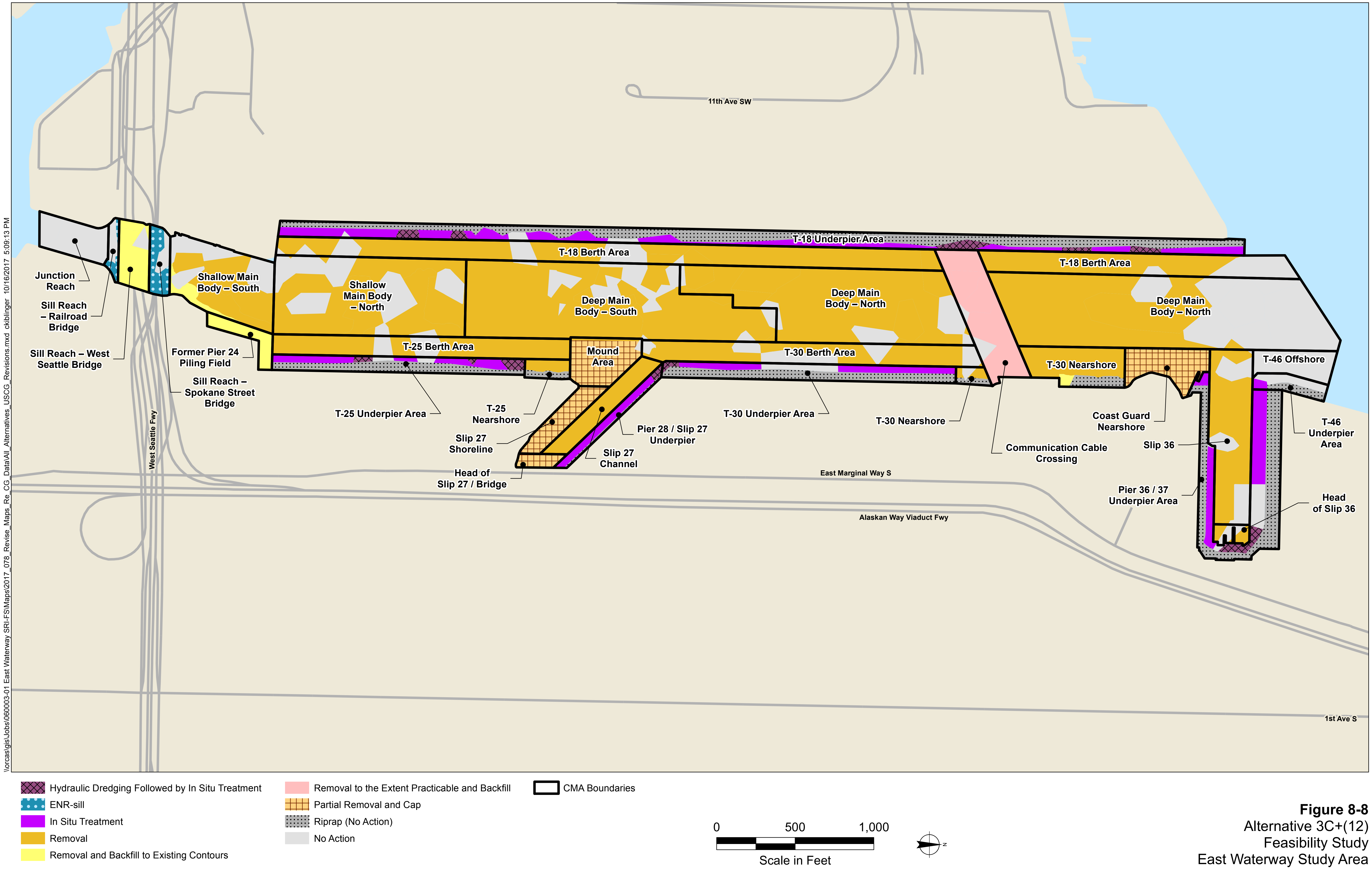
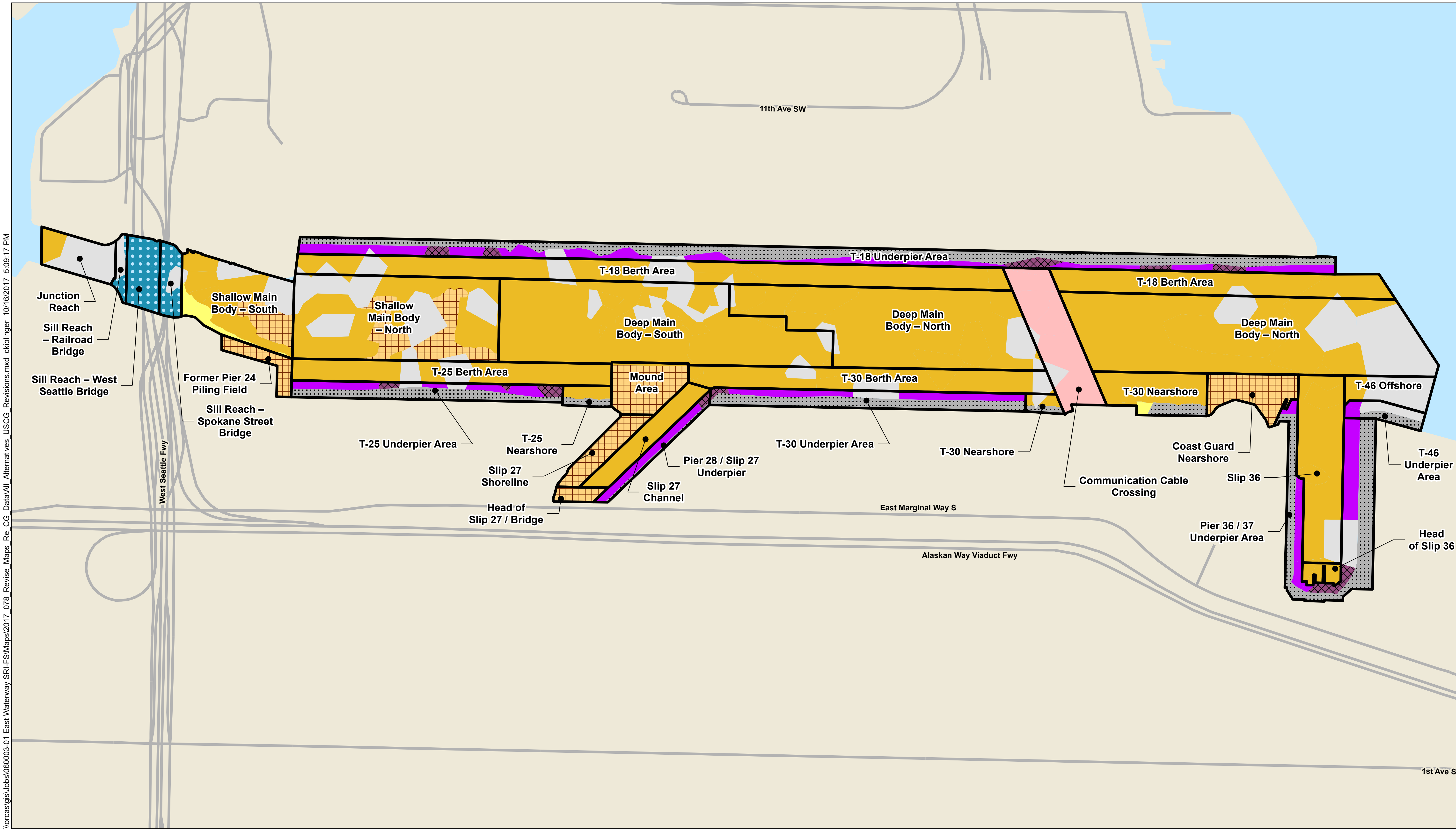


Figure 8-8
Alternative 3C+(12)
Feasibility Study
East Waterway Study Area



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Hydraulic Dredging Followed by In Situ Treatment
In Situ Treatment
Removal
Removal and Backfill to Existing Contours
Removal to the Extent Practicable and Backfill
Partial Removal and Cap
ENR-sill
Riprap (No Action)
No Action
CMA Boundaries

0 500 1,000
Scale in Feet

Figure 8-9
Alternative 2C+(7.5)
Feasibility Study
East Waterway Study Area

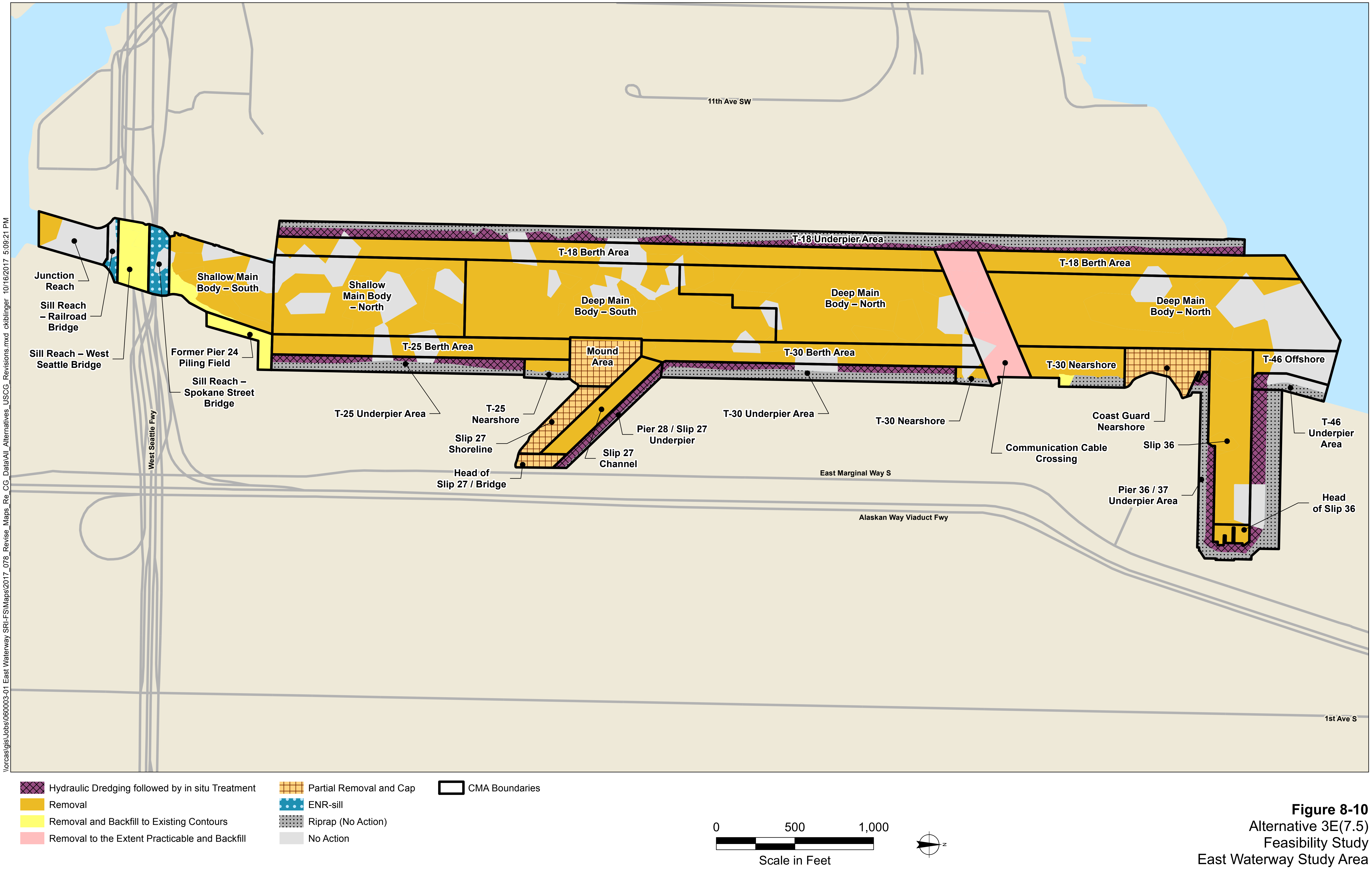

Figure 8-10
Alternative 3E(7.5)
Feasibility Study
East Waterway Study Area

9 DETAILED ANALYSIS OF ALTERNATIVES

This section presents a detailed analysis of the alternatives, using the FS criteria outlined in CERCLA and the NCP. As discussed in Section 8, these alternatives cover a representative range of potential remedial actions designed to satisfy the remedial action objectives for cleanup of the EW OU. A comparative evaluation of the alternatives under CERCLA occurs in Section 10.

9.1 Overview of National Contingency Plan Evaluation Criteria

The NCP requires consideration of nine evaluation criteria to address the CERCLA statutory requirements. The first two criteria are categorized as threshold criteria and must be met to be considered viable as a remedy for cleanup in the EW OU:

- Overall protection of human health and the environment
- Compliance with ARARs

The next five criteria are balancing criteria, which are weighed within the context of evaluating an alternative as a whole:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

These seven threshold and balancing criteria listed above form the basis for the detailed evaluation in this FS.

The last two criteria are modifying criteria, which are typically assessed following agency and public comment on EPA's Proposed Plan:

- State/tribal acceptance
- Community acceptance

The CERCLA criteria are used to evaluate each alternative. The key ideas and concepts embodied by the criteria and application to the specific circumstances of the EW are presented in the following subsections.

9.1.1 Threshold Criteria

CERCLA prescribes threshold criteria that must be met by an alternative. This section discusses how an alternative achieves these criteria, serves as a summary of how the EW alternatives meet the RAOs, and discusses what expected statutory or other relevant requirements must be achieved during implementation of the remedial action.

9.1.1.1 Overall Protection of Human Health and the Environment

This criterion addresses whether an alternative provides adequate protection of human health and the environment. EPA guidance (EPA 1988) states that the assessment of overall protection draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and short-term effectiveness. The assessment of overall protection provided for each alternative describes how site risks are eliminated, reduced, or controlled using treatment, engineering controls, institutional controls, or, more typically, a combination of these general response actions.

9.1.1.2 Compliance with ARARs

ARARs for cleanup of the EW OU were presented in Section 4.1. Two ARARs to evaluate the alternatives are discussed in this section: federal and state surface WQS (RCW 90-48 and WAC 173-201A, respectively) and MTCA including the Washington SMS (WAC 173-204), which apply to sediment cleanup sites. National recommended federal WQC developed to protect ecological receptors and human consumers of fish and shellfish are relevant and appropriate requirements pursuant to CERCLA Section 121 (d)(2)(A)(ii) and RCW 70.105D.030(2)(e).[93] More stringent state surface WQS apply where the state has adopted, and EPA has approved, WQS that are more stringent than the federal recommended WQC

[93] However, federal recommended ambient water quality criteria for consumption of organisms and water are not relevant because the EW is not a source of drinking water.

established under Section 304(a) of the CWA.[94] Both chronic and acute standards for marine water are used as appropriate.

The SMS are used to establish cleanup levels for sediment under MTCA and contain numerical criteria (SQS[95] and CSL) for the protection of biological resources, including benthic invertebrate organisms. The SMS also contains general methodology for developing numerical standards for the protection of human health and higher trophic level species and the process for complying with and achieving SMS requirements.

The other ARARs listed in Section 4 (Table 4-1) are not discussed explicitly as part of evaluating the alternatives. The alternatives (other than the No Action Alternative) are assumed to comply with these ARARs because the required engineering design, agency review process, and the tools within SMS[96] can ensure that the selected remedy will comply with the ARARs. For example, the construction elements for the alternatives are similar in nature and scope to sediment remediation projects previously implemented in the Puget Sound region and elsewhere around the country. 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). ARARs may affect implementation of the selected remedy but do not have a marked effect on whether an alternative is fundamentally viable. Further, the remedial design phase will address the

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[94] However, EPA proposed changes to the federal and state WQS in 2013, which are currently under review.

[95] The SMS list SQS as marine sediment quality standards (WAC 173-204-320). In addition, SMS has established numeric Sediment Cleanup Objective (SCO) for benthic organisms in WAC Section 173-204-562, where sediment cleanup standards are discussed. The rule also uses the term SCO to apply to standards based on protection of human health and higher trophic species (WAC Sections 173-204-561 and 173-204-564). For this reason, the term SQS has been retained for this FS and is synonymous with "SCO based on protection of the benthic community" in the SMS.

[96] Appendix A describes the SMS compliance process through which the selected alternative will meet the SMS ARAR over time either by meeting the PRGs in a reasonable restoration timeframe, or by adjusting the SCL upward once regional background levels are established for the geographic area of the EW and the attainment of those SCLs occurs in a reasonable restoration timeframe. A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

various land use and resource protection ARAR requirements (e.g., habitat preservation and mitigation).

Surface Water Quality Standards

Requirements for compliance with surface water quality ARARs during in-water construction are set in project-specific Section 401 Water Quality Certifications. These certifications generally require water quality monitoring at a compliance boundary located downstream of the construction area. Compliance with the requirements of Water Quality Certifications is expected to be met through the use of operational and structural BMPs.

Active remedial measures for the water column are not technically feasible and are therefore not included as part of the alternatives. While significant water quality improvements are anticipated from sediment remediation and source control, currently, upstream Green River and downstream Elliott Bay water concentrations are above federal recommended WQC for some chemicals, and therefore, it is not technically practicable for any alternative to meet all human health recommended federal or state ambient water quality criteria or standards that are based on human consumption of bioaccumulative contaminants (e.g., total PCBs and arsenic). EPA may determine that no additional practicable actions can be implemented under CERCLA to meet ARARs and issue a ROD Amendment or ESD providing the basis for a TI or other waiver for specified surface water quality-based ARARs under Section 121(d)(4) of CERCLA.

Model Toxics Control Act

As described in Section 4.3.1, MTCA regulations governing the selection of cleanup standards, among others, are ARARs under CERCLA. Sediment sites under MTCA are regulated by the SMS, which provides risk thresholds for specified exposure pathways (e.g., 1×10^{-6} excess cancer risk threshold for individual carcinogens to achieve the SCO), methods for setting the SCLs to appropriate levels up to the CSL (e.g., adjusting to regional background levels), and specific target concentrations for individual chemicals for protection of the benthic community. The PRGs were developed in Section 4.3 to be consistent with the SMS for protection of human health, the benthic community, and higher trophic level species. PRGs developed for RAOs 1 and 2 are consistent with the SMS for protection of human health, PRGs developed for RAO 3 are consistent with the SMS for protection of the benthic community, and PRGs developed for RAO 4 are consistent with the SMS for protection of higher trophic level species. The following paragraphs explain how the alternatives achieve the SMS ARAR for each RAO.

None of the action alternatives are predicted to achieve the natural background PRGs for RAO 1 for PCBs or dioxins/furans, based on modeling of the hypothetical maximum remediation scenario at the completion of cleanup implementation and modeling of long-term site-wide concentrations following source control of LDW and EW lateral inputs (see Appendix A). Long-term site-wide concentrations are driven primarily by the ongoing contribution of elevated concentrations from diffuse, nonpoint sources of contamination that contribute to regional background concentrations.

Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to meet and maintain natural background levels, regional background levels have not yet been established for the geographic area of the EW.

However, CERCLA compliance with MTCA/SMS ARARs may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations lower than current model predictions, and PRGs identified in this FS are attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Section 5 of Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition to these two potential MTCA/SMS ARARs compliance mechanisms, a final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

Because it is not known whether, or to what extent, the SMS ARARs for total PCBs and dioxins/furans will be achieved in the long term, the selection of which of the two compliance mechanisms described above (either meeting the natural background PRG in a reasonable restoration timeframe, or upwardly adjusting the SCL to regional background and meeting it in a reasonable restoration timeframe) is not identified at this time.

All alternatives (except for No Action) are predicted to meet the natural background-based RAO 2 PRG for arsenic of 7 mg/kg dw (based on the UCL95; EPA 2014) immediately after construction and may maintain this value in the long term, depending on incoming sediment concentrations (Section 9.15.1.2). However, modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above 7 mg/kg dw in the long term after construction, due to incoming sediment concentrations, meaning that the RAO 2 PRG for arsenic is predicted to be met only temporarily

The achievement of RAO 3 in this FS is estimated for key benthic risk driver COCs (total PCBs, arsenic, mercury, total HPAHs, total LPAHs, BEHP, and 1,4-dichlorobenzene), which serve as surrogate for the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA. The PRGs (the SQS or benthic SCO, based on SMS numerical criteria) are applied to these COCs on a point-by-point basis. For the purposes of the FS, an alternative's ability to achieve RAO 3 is approximated by at least 98% of existing surface (where potentially exposed from propwash) sediment sample locations with key benthic risk driver COC concentrations predicted to be below the PRGs. This metric acknowledges that the SMS has some flexibility in defining practicability for compliance with the SQS. In addition, the FS recognizes that, given the uncertainty in predictions of future contaminant concentrations based on model- and contaminant-specific assumptions, achievement of 100% compliance with the SQS may not prove to be practicable. Small numbers of SQS point exceedances may represent the potential for isolated minor adverse effects on the benthic community, and those do not necessarily merit further action based on a number of factors (such as sediment toxicity test results), as prescribed in the SMS. Adaptive management measures (e.g., verification monitoring, contingency actions) may become necessary, consistent with the technical feasibility provisions of the SMS, in response to isolated or localized SQS point exceedances. This metric is used for FS area and cost estimating purposes only and will not be used for determining post-cleanup compliance with the SMS.

All alternatives are predicted to achieve the RAO 4 PRGs.

9.1.2 Balancing Criteria

The following subsections describe the CERCLA balancing criteria and the metrics used to evaluate each criterion.

9.1.2.1 Long-term Effectiveness and Permanence

This balancing criterion evaluates the relative magnitude and type of residual risks that would remain at the site after remediation under each alternative. In addition, this criterion assesses the adequacy and reliability of the controls that are used to manage residual risks from contamination remaining at the site after remediation.

Magnitude and Type of Residual Risk

CERCLA RI/FS guidance refers to residual risk "…from untreated waste or treatment residuals at the conclusion of remedial activities," stating that the "…potential for this risk may be measured by the volume or concentration of contaminants in waste, media, or treatment residuals remaining on the site." Evaluation of this form of residual risk following remediation of the EW OU focuses on the potential for exposure of sediments that contain COCs above RALs. Each alternative considered two types of residual risk following cleanup.

The first type is the residual risks to humans, fish, and wildlife, and the benthic community from surface sediment contaminant concentrations remaining on site after the completion of remediation and over time. These were estimated for human health, fish and wildlife by using predicted site-wide SWACs over time derived from box model output, as described in Section 9.2.1. For the benthic community, a point mixing model was used to evaluate residual risk based on location-specific data, as discussed in Section 9.2.2. The second type of residual risk, which is the focus of the remainder of this subsection, is the risk from contaminated subsurface sediment that is left in place after remediation (e.g., under caps or in areas remediated by ENR-sill, partial removal and ENR-nav/ENR-nav, in situ treatment, or MNR), which might be transported to the surface through disturbance.

The magnitude and type of residual risk is evaluated in this FS with the following factors: potential disturbance of subsurface sediment and contamination remaining in subsurface after remediation.

Mechanisms for deep disturbance of subsurface sediment include vessels maneuvering under typical and extreme operations, ship groundings, operations such as pier construction/maintenance activities, or other types of scour, as described below:

- Construction is a main disturbance factor of subsurface sediment, but it is also a regulated activity that is expected to be managed through institutional controls.
- Natural erosion or scour from high-flow conditions in the EW was evaluated as part of the STE (Anchor QEA and Coast & Harbor Engineering 2012). As discussed in Section 5.1.4, it is anticipated that significant bed scour or erosion of in situ bed sediments within the EW are not predicted to occur as a result of tidal or riverine currents. The maximum predicted scour depths within the EW from vessel operations (including impacts from propwash and pressure fields) are presented in Section 5.1.5; surface sediments within the waterway have the potential to be eroded due to vessel operations throughout the majority of the EW, with predicted scour depths ranging from 0.3 to 4.7 feet.[97] Maneuvering of vessels used for construction may be managed through BMPs.
- Other types of scour that may occur in the EW (that were not modeled in the FS) include earthquake-induced movements of sediment and scour from flows larger than the Howard Hanson Dam's ability to regulate.[98] Earthquakes are mechanisms with the potential to expose subsurface contamination in both magnitude and duration sufficient to increase average surface sediment contaminant concentrations. As

[97] Based on both typical and extreme vessel operations.

[98] The Howard Hanson Dam is designed to manage flows at a 144-year return flood.

discussed in Section 2.14.5, earthquakes could expose subsurface contamination either directly as a result of the ground motion or indirectly (e.g., tsunamis). Earthquake effects are difficult to predict because the nature and magnitude of ground motions depend on earthquake type, location of the epicenter, and magnitude. Also, exposure of subsurface contamination is not the only means whereby surface sediment concentrations and associated risks can increase following an earthquake. Upland impacts caused by earthquakes, both laterally and upstream (e.g., spills, liquefaction of upland soils and sediment beds, landslides, slope failures), could affect post-earthquake surface sediment conditions.

The potential and magnitude of subsurface contaminant exposure from these disturbance mechanisms decreases as the concentration and area of subsurface contamination decrease and the depth to contamination increases. Two metrics were used in this FS to semi-quantitatively assess the magnitude of remaining subsurface contamination for each alternative, which focused on areas where exposure of subsurface sediment has the greatest potential to increase surface sediment concentrations. The metrics used included:

- **The number of sediment cores in the EW FS dataset that have COC concentrations above the RAL (or SQS) or CSL at any depth.** For each alternative, core counts with remaining contamination were reported separately for each of the technologies (partial removal and cap, in situ treatment, partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR) in order to discuss how the disturbance potential varies by technology. The FS dataset contains 146 cores locations with the majority of the data collected for the purpose of site-wide characterization, and therefore, the dataset is well distributed spatially and representative of the site as a whole. The number of cores remaining with RAL (or SQS[99]) or CSL exceedances in these locations is one indicator of subsurface contamination that would remain after implementation of each alternative and evaluates the post-construction potential to increase surface sediment concentrations in the event of exposure of subsurface contamination. The greatest exposure potential is from areas outside of the dredge and partial dredge and

[99] This analysis was based on RALs developed for the human health risk drivers, as well as a subset of the ecological risk drivers, which include TBT and a set of indicator SMS chemicals (i.e., selected risk driver contaminants detected above the SQS in surface sediments that represent the extent of SQS exceedances).

cap areas, with partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas having smaller potential than MNR areas. Even with some contamination remaining in these areas, proposed in situ treatment, MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas represent a minor contribution (1% to 12% depending on alternatives) to the overall EW remedial footprint for all alternatives, except for Alternatives with Open-water Option 1, where these technologies account for between 24% to 26% of the overall EW remedial footprint. However, the effect of exposure of subsurface contamination due to disturbance is anticipated to be minimal for these technologies for the following reasons:

- The majority of the remedial footprint area is addressed through removal technologies.
- Predictive modeling of impacts from disturbances indicates minimal effect to overall concentrations. Sediment mixing due to vessel scour has been incorporated into predictions of surface sediment concentrations in the FS (e.g., Table 9-1a). In scour areas (e.g., the navigation channel), the upper 0.5 to 2 feet of sediment is assumed to be mixed every 5 years. In underpier areas, sediment is assumed to be mixed with a portion exchanged with open-water areas every 5 years. Therefore, the predicted surface sediment concentrations account for the effect of vessel scour by assuming that subsurface sediment, surface sediment, and placed material (e.g., ENR material) are periodically mixed.
- Specification of aggregate mixes for ENR material can be designed and implemented to reduce impacts from the types of scour associated with typical and extreme vessel operations.
- Monitoring and adaptive management of these areas would trigger contingency actions if subsurface contamination is exposed.

- **Areas (acres) that are not removed and that, as a consequence, leave some degree of contamination in the subsurface.** Surface areas remediated by the various technologies serve as another relative indicator of the potential for exposing subsurface contamination because remedial technologies other than removal leave subsurface contamination in place. This metric does not imply that unacceptable subsurface contaminant concentrations necessarily exist across the full extent of areas where there is no removal. Nevertheless, more dredged areas within the EW represent less subsurface contamination that could potentially be exposed.

Although this analysis considered that exposure potential is equally important for capped, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas, caps are engineered systems with a higher degree of protectiveness, intended to ensure isolation and designed to handle location-specific conditions up to predetermined design thresholds.[100] The potential for subsurface sediment to be exposed by scour from propwash disturbances is greater beneath MNR, ENR-sill, partial removal and ENR-nav/ENR-nav, and in situ treatment areas, and depending on location, the appropriate technology is employed. However, proposed MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas represent a minor contribution (1% to 2% depending on alternatives) to the overall EW remedial footprint, except for Alternatives with Open-water Option 1 (where these technologies account for between 16% to 26% of the overall EW remedial footprint). All open-water areas, excluding areas with caps, are anticipated to have sediments vertically mixed as a result of propwash disturbances, and such mixing, dependent on vessel operation areas, has been incorporated into the long-term modeling. The potential for subsurface sediment to be exposed by propwash disturbances diminishes in severity and duration as natural recovery and further burial progress.

Appendix H describes the location-specific evaluations of the alternatives considered technology assignments, the extent of subsurface contamination removed, and the COCs responsible for subsurface sediment contamination remaining (defined for this analysis as detected contaminant concentrations exceeding the RAL). This valuable information can be used to evaluate the alternatives, review the dredging volume estimates, and plan location-specific remedial design investigations to refine the extent of subsurface contamination, and

[100] Based on preliminary cap modeling in Appendix D, a 5-foot-thick cap has been assumed, representing 1.5 feet of armor to protect from vessel scour, 1 foot of filter material, and 2.5 feet of isolation material, with an expected design life of more than 100 years. Thinner caps incorporating carbon/other treatment media may also be feasible. This will be evaluated during remedial design, along with seismic considerations. Contingency remedial actions include provisions for monitoring and adaptive management activities following an extreme disruptive event such as an earthquake/tsunami to assess potential impacts and to develop appropriate response actions to address any identified release.

the technology assignments during remedial design. Appendix H contains plan-view maps of the alternatives that provide a spatial distribution of remaining subsurface contamination and show the technology assignments and the subsurface contamination remaining at any depth with the SMS exceedance status for each core location following remediation. A summary of Appendix H with post-construction subsurface conditions (i.e., remaining subsurface contamination) is presented for each alternative under the long-term effectiveness and permanence criterion subsection (see Table 9-10).

These metrics are used to predict the area of remaining subsurface contamination following construction of each alternative and the magnitude of that remaining contamination.

Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage contaminated sediment that remains at the site. For the EW, this includes the following monitoring components:

- No Action Alternative – No Action assumes only a site-wide long-term monitoring program (to track the existing natural recovery processes).
- For the action alternatives, the amount of monitoring and maintenance is evaluated based on the areas undergoing remediation by capping, ENR-sill, partial removal and ENR-nav/ENR-nav, in situ treatment, and MNR. Areas that are dredged yield long-term or permanent risk reduction by removing contamination from the EW, but can result in short-term water quality impacts from dredging releases, such as the increased fish and shellfish tissue concentrations, the disturbance of the benthic community, and may potentially have longer term impacts from dredge residuals. Dredged areas will require management of post-removal residuals, either by placement of backfill/sand cover or natural recovery, but may require the least amount of long-term monitoring and maintenance. Areas that are capped yield more permanent risk reduction than those addressed by ENR-sill or partial removal and ENR-nav/ENR-nav, in situ treatment, or MNR and require moderate amounts of long-term monitoring and maintenance to ensure that subsurface contamination remains in place. MNR, ENR-sill, partial removal and ENR-nav/ENR-nav, and in situ treatment require a longer period of higher level of monitoring to track surface

sediment conditions over time until results indicate that contaminant concentrations have reached or are maintained at acceptable levels. In all cases, physical and chemical monitoring data will be used to determine the condition of the remedy as part of adaptive management. Repairs, such as thin-layer sand applications, could be needed or, if necessary, could involve engineered cap repairs or removal of contaminated sediment.

- EW-wide institutional controls are a required element of the action alternatives to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. As discussed in Section 7.2.2, an ICIAP for the EW would include a notification, monitoring, and reporting program for areas of the EW where contamination remains in place to ensure the performance of the remedy. This program may include elements such as proprietary controls and designation of RNAs to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. In addition, the ICIAP will include seafood consumption advisories and public outreach and education programs because none of the alternatives are predicted to achieve risk threshold concentrations that are below background concentrations.

For FS evaluation purposes, the adequacy and reliability of the controls (monitoring, maintenance, and institutional controls) are discussed based on the area remediated by capping, ENR-sill, partial removal and ENR-nav/ENR-nav, in situ treatment, and MNR.

9.1.2.2 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to reduce the toxicity, mobility, or volume of contaminants permanently and significantly. 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 alternative.

The NCP (40 CFR Section 300.430(a)(1)(iii)) states that EPA "generally shall consider the following expectations in developing appropriate 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."

EPA guidance 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 (EPA 1991b). No direct evidence has been found of non-aqueous phase liquids in EW sediments, and EPA has determined that contaminated sediments in the EW are low-level threat wastes (EPA 1991b).

The maximum concentrations detected for the four human health risk drivers in surface and subsurface sediment are: 184 ng TEQ/kg dw for dioxins/furans, 17,600 µg/kg dw for total PCBs, 241 mg/kg dw for arsenic, and 23,000 µg TEQ/kg dw for cPAHs (Section 2.11.2). Direct contact risks are much lower relative to seafood consumption risks (maximum site-wide direct contact RME total excess cancer risk is 5×10^{-6}, as compared to a total excess cancer risk of 1×10^{-3} for seafood consumption; see Tables 3-4a and 3-6). Based on EPA guidance, these COC concentrations classify as low-level threat waste because they are reliably contained and are near health-based levels (EPA 1991b).

This balancing criterion is designed to assess the degree to which alternatives comply with the preference for treatment in CERCLA, especially for material that qualifies as principal threat waste. Removal, capping, ENR-sill, partial removal and ENR-nav/ENR-nav, and MNR are not treatment technologies under CERCLA.[101] While these technologies reduce mobility and toxicity, they do not do so through treatment.

All alternatives (except for Alternative 1A(12)) include in situ treatment using activated carbon or other sequestering agents as a remedial technology in underpier areas. Activated carbon lowers the mobility of contaminants, reducing the toxicity and bioavailability to biological receptors directly in areas where it is applied and indirectly site-wide through reduced releases to the water column, which lowers average exposure to receptors. For this reason, alternatives with more area remediated by in situ treatment rank comparatively higher for this balancing criteria than alternatives relying on any non-treatment technologies.

9.1.2.3 Short-term Effectiveness

Short-term effectiveness addresses how an alternative affects human health and the environment during the construction phase of the remedial action and until RAOs are achieved. This criterion includes the protection of workers and the community during construction, environmental impacts that result from construction and implementation, and the length of time until RAOs are achieved.

Community and Worker Protection

Short-term impacts to human health are evaluated based on the following metrics:

- Local transportation impacts (traffic, noise, and air pollution) resulting from the implementation of the alternatives may affect the community and workers. In this FS, these impacts are assumed to be proportional to the number of truck, train, and barge miles estimated for support of material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, armor stone, and activated carbon used in capping, ENR-sill, partial removal and ENR-nav/ENR-nav, backfilling of dredged areas, RMC, and in situ treatment.

[101] Some biodegradation and dechlorination of organic compounds can be expected to occur in sediments over the long term. This mechanism is considered to yield limited risk reduction for more recalcitrant contaminants compared to the primary recovery mechanism of burial.

- Work-related accidents (injuries and deaths) may occur during the construction period and are proportional to the volume of material handled, use of diver-assisted hydraulic dredging, transportation requirements, and duration and type of remedial activities. Appropriate planning and adherence to standard health and safety practices will provide some protection to both workers and the community.

In addition, general disruptions and inconveniences to the public and commercial community (e.g., noise and lights from nighttime operations, increased street and vessel traffic, and potential temporary waterway restrictions) can be expected to increase with the duration of construction.

Environmental Impacts

Short-term impacts to the environment are evaluated based on the following metrics:

- **Dredged material resuspension and releases**: Resuspension of contaminated sediment is a well-documented short-term impact during dredging,[102] based on documented experience at other sites (Bridges et al 2010; NRC 2007; City of Tacoma and Floyd Snider 2007; BBL 1995a, 1995b; Bauman and Harshbarger 1998). Coarser resuspended material resettles, primarily onto the dredged surface and areas just outside the dredge footprint (near-field). Fine-grained material that is slow to resettle may be transported well beyond the dredge operating area (far-field). Dredging also releases contaminants into the dissolved phase (i.e., the water column). Dredging-related mass transfer can be reduced by using BMPs (e.g., silt curtains, debris removal, and equipment selection; see Section 7.5.3) but cannot be eliminated. Also, release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) are assumed to be managed through the placement of an RMC layer, similar in material and thickness as the ENR layer. As described in Section 8.1.6, the placement of the RMC sand layer is assumed to occur after all remedial activities are complete in areas where post-construction sampling and monitoring results show surface sediment concentrations are above RALs. However, short-term environmental impacts due to material resuspension may

[102] Resuspension can also occur to a lesser degree via man-made erosion events (e.g., propeller scour).

be mitigated by the placement of RMC, which would decrease the time required to achieve the RAOs.

- **Habitat and benthic community disturbance**: The degree of habitat disturbance is measured as the amount of remediation (e.g., removal, capping, ENR) in intertidal and shallow subtidal areas above -10 feet MLLW, which are critical habitat to outmigrating salmonids and important intertidal habitat. Dredging removes the existing benthic community, which must then recolonize in the biologically active zone and regain ecological functions following remediation.
- **Consumption of natural resources/energy:** The consumption of natural resources are the materials primarily in the form of quarry material (sand, gravel, and armor stone) and treatment material (activated carbon) used for in-water placement (e.g., capping, ENR-sill, partial removal and ENR-nav/ENR-nav, RMC, backfilling of dredged areas [where return to grade is assumed], and in situ treatment). The consumption of energy refers to thermal and electrical energy used during the implementation of alternatives (see Appendix I).
- **Landfill capacity utilization:** Represents the utilization of landfill space, which is proportional to the volume of dredged material removed and disposed of in the landfill, assuming a 20% bulking factor (see Appendix I).
- **Air pollutant emissions:** Estimates for air emissions based on heavy construction equipment and vehicle use and transportation are provided in Appendix I. Air pollutants include carbon dioxide (CO_2), particulate matter with a diameter below 10 and 2.5 micrometers (µm; PM_{10} and $PM_{2.5}$, respectively), carbon monoxide (CO), hydrocarbons (HCs), VOCs, nitrogen oxides (NO_x), and sulfur dioxide (SO_2).
- **Carbon footprint:** Defined as the forested area necessary to absorb the CO_2 produced during the remediation activities, based on the sequestration rate for Douglas fir trees (see Appendix I).

Time to Achieve RAOs

The time to achieve RAOs is defined as the time from when remedial construction begins to the time when PRGs are achieved.[103] The methodology applicable to each RAO used in this FS for estimating their time of achievement is listed below:

- **RAO 1 (Human Health - Seafood Consumption):** Long-term modeling results predict that none of the alternatives will achieve the RAO 1 natural background-based PRG for total PCBs and dioxins/furans. For FS purposes only, achieving 1×10^{-4} for the Adult Tribal RME, 1×10^{-5} for the Child Tribal RME, and 1×10^{-4} and 1×10^{-5} for the Adult API RME are used as risk reduction milestones for the time to achieve RAO 1 for these two risk driver COCs.
- **RAO 2 (Human Health - Direct Contact):** The time to achieve RAO 2 is the time to achieve the PRG for arsenic for the site-wide tribal netfishing and clamming direct contact RME exposure scenarios.
- **RAO 3 (Ecological Health-Benthic Organisms):** As discussed in Section 9.1.1.2, the metric used to assess the time to achieve RAO 3 is at least 98% of the existing surface (in areas exposed to propwash) sediment sample locations predicted to be below the RAO 3 PRGs for key benthic risk driver COCs.
- **RAO 4 (Ecological Health- Fish):** The time to achieve RAO 4 is the time to achieve the total PCB PRGs for English sole and brown rockfish.

The predicted outcomes are based on modeling and therefore, are subject to inherent uncertainties, primarily related to the incoming sediment concentrations associated with Green/Duwamish River and LDW inputs, the thickness and concentration of dredge residuals remaining, source control, sedimentation rate, the potential for contaminated subsurface sediments to be exposed in the future, the amount of sediment exchanged between open-water and underpier areas, and the efficacy of removal efforts (see Section 9.15 for more

[103] As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15), thus, the upper end of the number of work days in a construction season could increase to around 150 days/season, decreasing the total number of years of construction by about 2 years, consistently for all action alternatives. Therefore, times to achieve RAOs could be reduced compared to those presented in Section 9.

details). Many of these factors will be further addressed during remedial design. Specific design elements and actual construction timing and sequencing may affect conditions immediately following construction, and associated long-term changes in concentrations. Uncertainty bounds on time to achieve RAOs (using the metrics described above) were not estimated, but general modeling uncertainty considerations are addressed in Section 9.15.

9.1.2.4 Implementability

This criterion assesses the technical and administrative feasibility of implementing an alternative and the availability of services and materials required for implementation. Technical feasibility encompasses the complexity and uncertainties associated with the alternative, the reliability of the technologies, the ease of undertaking additional remedial actions if necessary, and monitoring requirements.

Administrative feasibility includes the activities required for coordination with other offices and agencies (e.g., consultation, obtaining permits for any off-site activities, or rights-of-way for construction). For example, a key administrative feasibility factor for the EW is that in-water construction is not allowed year-round in order to protect juvenile salmon and bull trout migrating through the EW. The Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15 (USACE 2015); however, based on recent project experience, this FS uses the typically permitted in-water construction window from October 1 to February 15 to avoid conflicts with tribal netfishing, potential adverse effects to migrating salmon, and for consistency with the commonly accepted construction window of upstream waters (e.g., the LDW construction window is October 1 to February 15). The in-water construction window will be confirmed by EPA in consultation with the National Marine Fisheries Service and U.S. Fish and Wildlife Service before implementation. In addition, coordination is necessary with the tribes, the Port of Seattle tenants, and other waterway users to ensure that impacts to their activities are minimized during remediation.

Availability of services and materials includes the availability of necessary equipment, materials, and specialists and the ability to obtain competitive bids for construction. Dredging and capping are mature technologies. Similar remedial and non-remedial (maintenance and construction) actions have been implemented in the EW and LDW and elsewhere in the Puget Sound region. Services, equipment, and materials (e.g., sand and aggregate) are locally or regionally available. Regional upland landfills are authorized to receive contaminated sediment and have done so on several recent projects in or near the EW. Presence of piles and debris is expected to complicate, but is not likely to significantly delay construction efforts.

All of the remedial technologies employed in open-water areas are technically implementable. The technical challenges associated with dredging include the stability of structures adjacent to removal operations, and efficiently dewatering and transloading sediments. Technical challenges associated with capping include evaluating slope stability, constructing for scour mitigation, and predicting rates of contaminant transport. Technical challenges for ENR are fewer than for dredging or capping, and include predicting remedial performance accounting for physical and chemical interactions with existing sediments.

Technical challenges are greater for active remediation under piers than for open-water areas.

In situ treatment has technical challenges associated with the selection and successful placement of stable material in difficult-to-access areas with steep slopes with pile and structural stability constraints. Material would be placed with conveyors, which involve more complex operations (compared to open-water placement) but have been used successfully both regionally and nationally (see Section 8.1.2.1).

Diver-assisted hydraulic dredging has the most technical challenges of any technology applicable in underpier areas. This form of dredging is the most difficult of the underpier technologies to implement where divers will be operating the dredge on steep slopes (1.75H:1V in most areas), composed of large riprap. Dredging will be conducted in deep water, which limits dive time for each diver and may require use of decompression chambers (as required by commercial diving regulations), resulting in a large team of divers to complete the work over a period of months and years. Technical challenges are also associated with low visibility as a result of shade from the pier, water depth, and sediments suspended as part of the dredging, making the work more hazardous from a worker health and safety perspective. Debris, such as cables, large wood, and broken pilings, will also complicate the dredging and potentially generate more unsafe conditions. Technical challenges are also present with respect to the infrastructure, such as existing piling and cross bracing, which will require relocation of both floating and submerged lines into and out of each bent.

In addition, hydraulic dredging generates large quantities of slurry (sediment/water) that must be treated prior to discharge back to the waterway. Upland areas are not available for slurry storage, sediment settling, effluent treatment, testing, and discharge because of Port operations at existing terminals. Pipeline transport of the slurry to an upland staging location is also not feasible because of impacts to navigation and long pipeline transport distances in the waterway. Therefore, it is most likely that the sediment slurry will need to be handled using a portable treatment system on a barge, which limits the daily production rate and complicates the water containment, dewatering, and treatment.

Underpiers are adjacent to active berthing areas, which have averaged around 300 container ships per year and 600 total vessel calls per year in the EW. Diving schedules are likely to be significantly impacted by waterway activities, which could result in delays in completing the work. In particular, dive time may be further limited to specific diving windows, due to risks posed to divers from propwash and suction forces from transiting and berthing container vessels. Similarly, more business interruption will occur as a result of hydraulic dredging because of restricted access to areas where divers are performing underwater work. In addition, all retained diver-assisted hydraulic dredging alternatives also include the application of in situ treatment material following dredging to remediate residuals. Therefore, diver-assisted dredging also includes implementability challenges associated with underpier in situ treatment. MNR has no technical challenges in underpier areas. MNR has the lowest potential for difficulties and delays and impacts to EW tenants and users. However, MNR has the largest potential for contingency actions in the future, should the cleanup goals not be met. In addition, monitoring will be more technically challenging under piers than in open-water areas for both MNR and the active remedial technologies.

In addition to underpier remediation, all alternatives are subject to common technical implementability challenges, such as the following:

- The EW is a busy working industrial waterway, which may require locating a transloading facility elsewhere that will have to be sited and permitted.

- Careful coordination will be required among the Port, waterway users, and government agencies to design, schedule, and construct the cleanup actions.
- It will be important to evaluate whether source controls have been implemented to a sufficient degree before or as a part of remedy construction (e.g., to stabilize erodible embankments) to limit recontamination potential.

Institutional controls are a requirement of all action alternatives to manage human health risks from seafood consumption (Section 8.1.2.6). Notification, monitoring, and reporting programs (including proprietary controls and designation of RNAs) are mechanisms that will be used to protect capped, ENR-sill, partial removal and ENR-nav/ENR-nav, and MNR areas, where contamination is left in place, to ensure the performance of the remedy; therefore, they are an additional factor to consider with respect to administrative implementability of the alternatives. Other control mechanisms include seafood consumption advisories used in conjunction with public education and outreach programs. These controls are difficult to monitor and are not enforceable and are therefore generally understood to have limited effectiveness. One objective of the public education/outreach effort is to improve compliance with the advisories.

CERCLA guidance indicates that institutional controls should be relied upon only to the minimum extent practicable. These programs would likely be developed and administered by the responsible parties with EPA oversight and with participation from local governments, tribes, and other community stakeholders.

CERCLA guidance also considers the reliability of the remedial technologies as part of implementability. Dredging and capping are considered the most reliable remedial technologies because they isolate the most contamination. ENR and in situ treatment are less reliable because they rely on more complicated chemical and physical processes, such as sedimentation and contaminant adsorption. MNR is less reliable still because it relies entirely on natural processes.

Metrics used to gauge the relative magnitude of technical and administrative implementability of the alternatives include the surface areas remediated and the dredge volumes by dredge type because areas and volumes are considered proportional to the degree of difficulty to implement and manage them. Acreage subject to MNR represents only 8% of the EW area (only Alternative 1A(12) uses MNR technology) is also considered because it requires significant administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if needed.

9.1.2.5 Cost

The cost criterion evaluates the construction and non-construction costs of each alternative. Construction costs include mobilization/demobilization, other pre-construction activities (such as preparation of staging and stockpile areas and site control), removal, dewatering, offloading, disposal, material placement (engineered capping, RMC, and in situ treatment material), surveys, monitoring, sales tax, and contingency. The non-construction costs include design and permitting, project management, environmental compliance (pre-construction baseline monitoring, construction monitoring and confirmational sampling, and post-construction performance monitoring), and agency review and oversight.

Costs for contingency are included as a percentage of the construction costs (30%) to cover unknowns, unforeseen circumstances, and unanticipated conditions reducing the overall risk of cost overruns. They also include costs for contingency remedial actions to address the potential that some areas assumed in the FS to be suitable for no action or less aggressive technologies (e.g., ENR-sill, partial removal and ENR-nav/ENR-nav, or MNR) will require dredging based on information gained either during remedial design or as a result of long-term monitoring (see Appendix E).

Consistent with CERCLA guidance, the cost estimates were prepared in the absence of detailed engineering design information. The amount and quality of remedial investigation data used to develop and scope alternatives correspond to an expected accuracy for FS cost estimates of approximately -30% to +50% (EPA 2000a). Costs provided in Appendix E are intended to fall within this range of accuracy.

The cost estimates developed in this FS are net present value (NPV) and expressed in 2016 dollars.

9.1.3 Modifying Criteria

The final two detailed evaluation criteria are the modifying criteria: state and tribal acceptance and community acceptance.

EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance of the selected remedial action in the ROD following the public comment period on EPA's Proposed Plan.

9.2 Estimation of Sediment Contaminant Reduction Over Time

Performance of the alternatives with respect to long-term effectiveness, permanence, and recontamination is, in part, evaluated based on reductions in surface sediment concentrations (and therefore residual risk to humans and ecological receptors) at the completion of construction and over time. For each alternative, three predictive model evaluations were conducted: the box model, the point mixing model, and the grid model evaluations. Sections 5.3 through 5.5 present a detailed description of each of these predictive models, and Appendix J (Sections 2, 3, and 4) provides the specific inputs, mathematical calculations, and uncertainty considerations associated with each analysis. Sections 9.2.1, 9.2.2, and 9.2.3 provide a brief description of how the box, point mixing, and grid model evaluations were conducted. In addition to these evaluations for predicting sediment concentrations, general approaches for estimating tissue concentrations of total PCBs and dioxins/furans post-remedy are presented in Section 9.2.4.

9.2.1 Box Model Evaluation: Site-wide and Area-specific SWAC Output

The box model evaluation was conducted to predict the EW site-wide and area-specific SWACs over time for the four human health risk driver COCs for each alternative and were used to evaluate their performance against the PRGs for RAO 1 (total PCBs and dioxins/furans, site-wide; cPAHs in tribal clamming areas[104]), RAO 2 (arsenic site-wide and

[104] As discussed in Section 3.3.4, the clam tissue-to-sediment relationship for cPAHs in the EW based on the SRI data was too uncertain to develop a sediment RBTC, and therefore, an RAO 1 PRG for cPAHs was not developed (Windward and Anchor QEA 2014). Variables other than localized sediment concentrations are likely to be important factors in determining cPAH tissue concentrations, based on the filter-feeding behavior

in tribal clamming areas), and RAO 4 (total PCBs, site-wide). This model is based on anticipated solids deposition and sediment bed mixing (from propwash and bioturbation) in the EW and because the model output was site-wide or clamming area SWACs, it assumed that sediment deposition (from upstream and lateral sources) occurs evenly throughout the EW and that the net sedimentation rate (NSR) is constant throughout the EW (Section 5.3).

The box model evaluation calculates the site-wide SWAC by dividing the EW into sub-areas based on remedial technology and estimated mixing depth (Figures 5-4 and 5-5) so that those variations are accounted for. The site-wide and clamming SWACs were predicted as a function of time every 5 years (0 to 40 years post-remediation).

9.2.2 Point Mixing Model Evaluation: Point Output

The point mixing model evaluation was conducted to predict the EW point surface concentrations over time in MNR areas using surface and, where subject to propwash, shallow subsurface (0 to 2 feet) sediment concentrations. The analysis was conducted using seven key benthic risk driver COCs (total PCBs, arsenic, mercury, total HPAHs, total LPAHs, BEHP, and 1,4 dichlorobenzene)[105] to evaluate compliance with RAO 3 for each alternative. As discussed in Section 5.5, achievement of RAO 3 is evaluated at all (342) sample locations throughout the EW. Point mixing model predictions were conducted for 18 locations within areas planned for MNR (under piers and under bridges). All other locations are expected to meet RAO 3 PRGs following construction, either through active remediation or because they are currently below RAO 3 RALs/PRGs. These point-based concentrations were used to

of clams, thus, any potential effect of sediment remediation on concentrations of cPAHs in clam tissue is highly uncertain. Long-term clam tissue monitoring following sediment remediation and source control may be needed to determine whether (and to what extent) decreases in cPAH concentrations in sediment result in decreases in cPAH concentrations in clam tissue. Despite these practical limits and uncertainties in remedial performance, risks can be reduced through a combination of remediation, source control, and institutional controls, with institutional controls being used only to the extent that additional remedial measures cannot practicably achieve further risk reduction.

[105] The key benthic risk drivers serve as a surrogate for all of the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA (Windward 2012a). Total PCBs and arsenic are also human health risk drivers.

evaluate the performance of alternatives against the RAO 3 PRGs by estimating the percentage of surface and shallow subsurface sediment locations predicted to be below the PRG (RALs) with respect to the total sediment locations. This model is based on anticipated solids deposition and vertical mixing assumptions (Section 5.5).

The point surface concentrations were predicted as a function of time (0 to 40 years post-remediation) in 5-year intervals, and the percentage of surface sediment locations below the RAO 3 PRGs were reported over time. The results were also compared to benthic CSL in Section 9.3.1 for context.

Predicted surface sediment point concentrations and spatial distributions of the point exceedances over time and for the key risk driver COCs are provided in Appendix J.

9.2.3 Grid Model Evaluation: Recontamination Potential

Recontamination potential evaluation following remedial actions was conducted by using a gridded model to predict spatial distributions of surface concentrations deposited from upstream and lateral inputs in the EW over time. The purpose was to determine the potential for discrete areas within the EW where deposited sediment concentrations may exceed RALs so that areas with recontamination potential are identified. This will inform future source control efforts and general areas where post-construction monitoring can be targeted. The recontamination potential evaluation was estimated throughout the EW by using the results of numerical modeling (i.e., PTM) as an input to a GIS-based grid model[106] to estimate deposited sediment concentrations post-remediation (years 1 to 40 post-remediation) in 5-year intervals for nine key risk driver COCs[107] (Section 5.4 and Appendix J).

The calculated concentrations of deposited material in each grid cell were used to determine areas within the EW with the potential to exceed RALs. These areas will be considered during design as areas that could be subject to further source evaluation and control efforts and

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[106] The grid model divides the EW into contiguous square cells with a 50-foot x 50-foot resolution for use in the recontamination evaluation (Grid Model Evaluation).

[107] The nine key risk driver COCs include: total PCBs, cPAHs, dioxins/furans, arsenic, mercury, HPAHs, LPAHs, BEHP, and 1,4-dichlorobenzene.

possible post-remediation monitoring. An overall summary of recontamination potential for all the alternatives is discussed in Section 9.14, with detailed results provided in Appendix J.

9.2.4 Predicted Post-remedy Tissue Concentrations

An FWM (for total PCBs) and species-specific BSAFs (for dioxins/furans) were developed as part of the SRI (Windward and Anchor QEA 2014) to estimate relationships between concentrations in surface sediment and seafood tissue.[108] In addition to being used to calculate sediment RBTCs in Section 3.3 (also see Section 8 and Appendix C of the SRI), these tools were used to predict post-remedy tissue concentrations for these two contaminants to allow for an assessment of residual risks to support the detailed and comparative evaluation of alternatives with respect to achieving RAO 1 (Section 9.3). The subsections that follow briefly discuss the use of the FWM and species-specific BSAFs for this application.

9.2.4.1 Food Web Model

As discussed in Section 3.3.4, the EW FWM was developed in consultation with EPA (see Appendix C of the SRI [Windward and Anchor QEA 2014]) and its application for the calculation of post-remedy tissue concentrations is consistent with the approach used in the LDW FS (AECOM 2012).

For the purpose of calculating post-remedy tissue concentrations, the two key input values are the concentration of total PCBs in surface sediment (represented by the SWAC) and in surface water. The current (baseline) conditions for these parameters are as follows:

- **Surface sediment** – The surface sediment SWAC for total PCBs for the EW has been estimated to be 460 μg/kg dw.
- **Surface water** – The EW-wide mean total PCB concentration measured in water was 1.31 nanograms per liter (ng/L), and the calibrated value was 1.16 ng/L.

In the future, total PCB concentrations in sediment and water are expected to be lower following sediment remediation and source control actions within the EW.

108 As discussed in Section 3.3.4, a tissue to sediment relationship could not be developed for cPAHs (the other seafood consumption risk driver), and thus post-remedy cPAH tissue concentrations were not calculated.

As was the case for the LDW, it is important to note that there is uncertainty associated with using the FWM to predict post-remedy tissue concentration since the model was calibrated based on existing conditions for sediment, tissue, and water.

Changes in total PCB surface sediment SWACs were predicted for each alternative over time using the box model evaluation (Sections 5.3 and 9.2.1). Predictions of total PCB concentrations in the water column were determined using best professional judgment based on ranges of total PCBs in sediment. Three different total PCB water concentrations were used, as described below. This approach is consistent with that used for the LDW FWM[109] (Windward 2010a).

- **Total PCB concentration of 0.6 ng/L in water** – This value was used in the FWM when the total PCB concentration in the surface sediment was less than 100 µg/kg dw. This water concentration was estimated by considering model output derived from King County's Environmental Fluid Dynamics Code (EFDC) model (Windward 2010a). This water concentration was used for the majority of the residual risk analyses.
- **Total PCB concentration of 0.9 ng/L in water** – This value was used in the FWM when the total PCB concentration in surface sediment was between 100 and 250 µg/kg dw. This water concentration was selected as an intermediate value between 0.6 and 1.2 ng/L.
- **Total PCB concentration of 1.2 ng/L in water** – This value was used in the FWM when the total PCB concentration in surface sediment was between 250 and 470 µg/kg dw. This water concentration was assumed to represent baseline conditions (equal to the calibrated water concentration for the EW FWM [1.16 ng/L] and slightly below the EW-wide mean concentration of 1.31 ng/L).

The porewater concentration parameter (estimated by the model) provides a mechanism for the FWM to account for the potentially higher concentrations of total PCBs at the sediment-water interface. Appendix C of the SRI provides basis and assumptions used to calibrate the EW FWM for the estimated total PCB concentrations in surface sediment and overlying water column.

[109] There are, however, differences in the flow regimes and inputs for the two waterways (e.g., the Green River is contiguous with the LDW, the EW is contiguous with Elliott Bay, and the residence time of water is longer in the LDW than in the EW). Hence, there is uncertainty in applying the assumptions about the relationship between total PCBs in water and sediment developed for the LDW to the EW.

9.2.4.2 Biota-sediment Accumulation Factor

As discussed in Section 3.3.4, site-specific dioxins/furans BSAFs for four target species (three fish and one crab) were developed as part of the SRI to calculate sediment RBTCs for the human health seafood consumption scenarios (details are presented in Section 8 and Appendix C of the SRI [Windward and Anchor QEA 2014]). As was done for the FWM and total PCBs, these BSAFs were used in this FS to calculate post-remedy tissue concentrations for the evaluation of post-remedial risks using the predicted post-remedy sediment concentrations from the box model evaluation (Section 9.2.1).

The key assumption with the use of the BSAF approach (either to calculate sediment RBTCs or post-remedy risk estimates) is that the dioxin TEQ composition patterns remain consistent in the future for sediment, both within the various tissue types and across species. It is unknown whether these relationships will change in the future, and thus there is uncertainty in the application of these BSAFs for predicting post-remedy tissue concentration. Additional uncertainties associated with the dioxins/furans BSAFs are discussed in the SRI (Windward and Anchor QEA 2014).

9.3 Site-wide and Area-specific SWAC and Risk Reductions

Risk driver concentrations in sediment following remediation are metrics for evaluating long-term effectiveness and permanence of the alternatives. Estimates of residual risk based on these sediment concentrations provide additional information on long-term effectiveness following remediation. This section summarizes estimates of site-wide and area-specific SWACs and risks over time for each alternative. These model results used the base case chemistry assumptions that were developed and presented in Section 5, based on sensitivity and bounding evaluations described in Appendix J. However, following implementation of the selected remedy, compliance will be determined using a UCL95 rather than a SWAC for area-wide exposure areas.

9.3.1 Reduction in Sediment Bed Concentrations

Tables 9-1a and 9-2 contain the site-wide SWACs predicted using the box model output for total PCBs, dioxins/furans, and arsenic; in addition, SWACs for clamming areas are presented in Tables 9-1b and 9-2 for arsenic and cPAHs, respectively, as they were identified as human health risk drivers for clam consumption (cPAHs) and direct sediment contact during clamming (arsenic). The results are tabulated as a function of time (years 0 to 40), with year 0 being the completion of construction of each alternative (construction durations are also shown on Tables 9-1a, 9-1b, and 9-2 for perspective). The No Action Alternative has no remedial actions but provides a basis to compare the relative effectiveness of the other alternatives.

Time trends of site-wide SWACs from Tables 9-1a, 9-1b, and 9-2 are presented in Figures 9-1a, 9-1b, and 9-1c. Arsenic and cPAH SWACs in clamming areas from Tables 9-1b and 9-2 are shown in Figures 9-2a and 9-2b. Table 9-3 presents predicted percentages of sediment locations below the PRGs for the key benthic risk drivers over time.

The following general observations can be made from information presented in the foregoing tables and figures:

- **RAO 1 (Tables 9-1a and 9-1b; Figures 9-1a, 9-1b, and 9-2b)**
  - At year 40 after construction completion, site-wide SWACs for total PCBs and dioxins/furans are predicted to reach very similar values for Alternatives 1B(12) through 3E(7.5), a consequence of incoming upstream sediment from the Green/Duwamish River and remediation footprints that all emphasize removal. Alternative 1A(12) would take longer than 40 years to approach similar values as the other action alternatives.
  - For the action alternatives, SWACs increase for total PCBs and dioxins/furans from year 0 to 5 (after construction completion) as a result of two key assumptions that result from vessel propwash: 1) mixing of RMC with underlying dredge residuals in portions of the EW, and 2) exchange of resuspended underpier sediments with open-water sediments. The extent of mixing and exchange was approximated in consultation with EPA and may not accurately capture the actual impact to SWAC, but it is an appropriate assumption for the comparison of alternatives in the FS (see Appendix J for vertical mixing and volume exchange assumptions, and sensitivity/bounding evaluations).

Table 9-1a
Predicted Long-term Site-wide SWACs for Risk Drivers for RAOs 1 and 4

Total PCB Site-wide SWACs (µg/kg dw) (RAOs 1 and 4)

Alternative	Construction Time (years)	Site-wide (Seafood Consumption) Baseline SWAC = 460[a] Human Health PRG (Natural Background) = 2[b] Ecological (Fish) PRG = 250/370[c]								
		Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	604	410	326	281	251	229	210	194	180
1A(12)	9	76	131	126	114	103	95	87	82	77
1B(12)	9	40	71	71	68	65	63	60	59	57
1C+(12)	9	40	65	65	63	61	59	57	56	54
2B(12)	10	42	72	71	68	65	63	60	59	57
2C+(12)	10	42	65	65	63	61	59	57	56	55
3B(12)	10	43	71	71	68	65	63	60	59	57
3C+(12)	10	43	65	65	63	61	59	57	56	55
2C+(7.5)	11	39	63	63	61	59	57	56	55	54
3E(7.5)	13	41	56	56	55	53	52	52	51	50

Dioxin/Furan Site-wide SWACs (ng TEQ/kg dw) (RAO 1)

Alternative	Construction Time (years)	Site-wide (Seafood Consumption) Baseline Mean = 15.7[d] Human Health PRG (Natural Background) = 2[e]								
		Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	15.0	12.2	10.9	10.1	9.6	9.2	8.9	8.6	8.4
1A(12)	9	4.1	7.0	7.2	7.1	6.9	6.8	6.7	6.6	6.5
1B(12)	9	3.2	5.3	5.6	5.8	5.8	5.9	5.9	5.9	5.9
1C+(12)	9	3.2	5.3	5.7	5.8	5.8	5.9	5.9	5.9	6.0
2B(12)	10	3.2	5.3	5.6	5.7	5.8	5.8	5.9	5.9	5.9
2C+(12)	10	3.2	5.3	5.6	5.8	5.8	5.9	5.9	5.9	5.9
3B(12)	10	3.3	5.2	5.6	5.7	5.8	5.8	5.9	5.9	5.9
3C+(12)	10	3.3	5.2	5.6	5.7	5.8	5.8	5.9	5.9	5.9
2C+(7.5)	11	3.0	5.1	5.5	5.6	5.7	5.7	5.8	5.8	5.8
3E(7.5)	13	3.1	5.1	5.5	5.7	5.8	5.8	5.9	5.9	5.9

Notes:

a. Baseline SWAC based on surface sediment data collected from the EW and calculated on the IDW interpolated total PCB concentrations throughout the waterway, as reported in the SRI (Windward and Anchor QEA 2014).

b. The natural background value presented for total PCBs is the UCL95 using the OSV *Bold* Survey (DMMP 2009) dataset (LDW ROD; EPA 2014). See Section 4 for detailed rationale.

c. Two PRGs have been established in Section 4 based on brown rockfish (250 µg/kg dw) and English sole (370 µg/kg dw).

d. Baseline mean based on subtidal composite surface sediment data collected from the EW for dioxins/furans, as reported in the SRI (Windward and Anchor QEA 2014).

e. PRG presented for dioxins/furans is the natural background value (UCL95, using the OSV Bold Survey [DMMP 2009] dataset [LDW ROD]; EPA 2014). See Section 4 for detailed rationale.

Colored cells indicate achievement of Ecological PRGs for brown rockfish and English sole.

Colored cells indicate achievement of Ecological PRG for brown rockfish.

1. SWACs generated using the box model evaluation. Box model predictions use base case chemistry assumptions that were developed and

2. Chemistry inputs from upstream and lateral, as well as replacement values are presented in Section 5 for total PCBs and dioxins/furans.

3. Year 0 post-construction SWACs are estimated considering the likely widespread placement of clean sand (residuals management cover). The

DMMP – Dredged Material Management Program; EW – East Waterway; FS – Feasibility Study; IDW – inverse distance weighting; LDW – Lower Duwamish Waterway; PRG – preliminary remediation goal; RAO – remedial action objective; ROD – Record of Decision; SRI – Supplemental Remedial Investigation; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence limit on the mean

Table 9-1b
Predicted Long-term Clamming SWACs for cPAHs

cPAH Clamming SWACs (µg TEQ/kg dw) (RAO 1)

Alternative	Construction Time (years)	Clamming Areas Baseline Mean = 1,900[a]								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	1161	527	308	226	195	181	174	169	166
1A(12)	9	19	186	185	176	168	161	157	154	151
1B(12)	9	19	136	146	146	144	143	142	142	141
1C+(12)	9	19	132	143	143	143	142	141	141	140
2B(12)	10	19	136	146	146	144	143	142	142	141
2C+(12)	10	19	132	143	143	143	142	141	141	141
3B(12)	10	28	129	144	145	144	143	142	141	141
3C+(12)	10	28	124	140	142	142	142	141	141	140
2C+(7.5)	11	20	124	136	138	138	138	138	138	138
3E(7.5)	13	28	116	134	138	140	140	140	140	140

Notes:

a. Baseline mean based on area-wide intertidal MIS composite surface sediment data collected from the EW for cPAHs, as reported in the SRI (Windward and Anchor QEA 2014).

1. SWACs are shown for informational purposes. cPAHs are a risk-driver COC for RAO 1 based on consumption of clams. However, a PRG was not developed because the clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop a sediment RBTC based on clam consumption (see Section 3.3.4).

2. SWACs generated using the box model evaluation. Box model predictions use base case chemistry assumptions that were developed and presented in Section 5.

3. Chemistry inputs from upstream and lateral sources, as well as replacement values, are presented in Section 5 for cPAHs.

µg – microgram; DMMP – Dredged Material Management Program; dw – dry weight; EW – East Waterway; IDW – inverse distance weighting; kg – kilogram; mg – milligram; MIS – multi-increment sampling; PRG – preliminary remediation goal; RAO – remedial action objective; RBTC – risk-based threshold concentration; ROD – Record of Decision; SRI – Supplemental Remedial Investigation; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence limit on the mean

Table 9-2
Predicted Long-term Site-wide and Clamming SWACs for Arsenic for RAO 2

Arsenic Site-wide and Clamming SWACs (mg/kg dw) (RAO 2)

Alternative	Construction Time (years)	Site-wide Baseline SWAC = 8.8[a] Netfishing PRG (Natural Background) = 7[b]									Clamming Areas Baseline Mean = 10[c] Tribal Clamming PRG (Natural Background) = 7[b]								
		Time After Construction (years)									**Time After Construction (years)**								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	10.1	9.8	9.6	9.5	9.5	9.4	9.4	9.3	9.3	9.4	9.3	9.3	9.2	9.2	9.2	9.2	9.1	9.1
1A(12)	9	4.5	7.1	7.7	7.9	8.0	8.1	8.2	8.2	8.3	2.3	8.3	8.8	8.9	8.9	8.9	8.9	8.9	8.9
1B(12)	9	4.4	7.1	7.6	7.8	8.0	8.0	8.1	8.2	8.2	2.3	8.2	8.7	8.8	8.9	8.9	8.9	8.9	8.9
1C+(12)	9	4.4	6.8	7.4	7.7	7.8	7.9	8.0	8.1	8.2	2.3	8.0	8.6	8.8	8.8	8.8	8.8	8.8	8.8
2B(12)	10	4.4	7.0	7.6	7.8	7.9	8.0	8.1	8.2	8.2	2.3	8.2	8.7	8.8	8.9	8.9	8.9	8.9	8.9
2C+(12)	10	4.4	6.8	7.4	7.7	7.8	7.9	8.0	8.1	8.2	2.3	8.0	8.6	8.7	8.8	8.8	8.8	8.8	8.8
3B(12)	10	4.6	6.9	7.5	7.8	7.9	8.0	8.1	8.1	8.2	3.1	7.9	8.6	8.8	8.9	8.9	8.9	8.9	8.9
3C+(12)	10	4.5	6.7	7.3	7.6	7.8	7.9	8.0	8.1	8.2	3.1	7.7	8.5	8.7	8.8	8.8	8.8	8.8	8.8
2C+(7.5)	11	4.3	6.7	7.3	7.6	7.8	7.9	8.0	8.1	8.1	2.3	8.0	8.6	8.7	8.8	8.8	8.8	8.8	8.8
3E(7.5)	13	4.3	6.3	7.1	7.5	7.7	7.9	8.0	8.1	8.2	3.1	7.6	8.4	8.7	8.9	8.9	8.9	9.0	9.0

Notes:

a. Baseline SWACs based on surface sediment data collected from the EW and calculated on the IDW interpolated arsenic concentrations throughout the waterway, as reported in the SRI (Windward and Anchor QEA 2014).

b. The natural background value presented for arsenic is the UCL95 using the OSV *Bold* Survey (DMMP 2009) dataset (LDW ROD; EPA 2014). See Section 4 for detailed rationale.

c. Baseline mean based on area-wide intertidal MIS composite surface sediment data collected from the EW for arsenic as reported in the SRI (Windward and Anchor QEA 2014).

Colored cells indicate achievement of PRGs.

1. SWACs generated using the box model evaluation. Box model predictions use base case chemistry assumptions that were developed and presented in Section 5.

2. Chemistry inputs from upstream and lateral sources, as well as replacement values, are presented in Section 5 for arsenic.

DMMP – Dredged Material Management Program; dw – dry weight; EW – East Waterway; IDW – inverse distance weighting; kg – kilogram; mg – milligram; MIS – multi-increment sampling; PRG – preliminary remediation goal; RAO – remedial action objective; RBTC – risk-based threshold concentration; ROD – Record of Decision; SRI – Supplemental Remedial Investigation; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence limit on the mean

Table 9-3
Predicted Percentages of Sediment Locations Below PRGs and CSL
for Key Benthic Risk Drivers Over Time (RAO 3)

Percent Locations Below PRGs

Alternative	Construction Time (years)	COC	Time After Construction (years) 0	5	10	15	20	25	30	35	40
No Action	-	All 7 key benthic risk drivers	22%	nc	nc	nc	nc	nc	nc	nc	nc
1A(12)	9	Mercury	98%	98%	99%	100%	100%	100%	100%	100%	100%
		BEHP	98%	99%	99%	99%	99%	99%	99%	99%	99%
		1,4-DCB	99%	99%	99%	99%	99%	99%	99%	99%	99%
		Total PCBs	96%	96%	97%	97%	97%	97%	98%	98%	99%
		All other key benthic risk drivers	100%	100%	100%	100%	100%	100%	100%	100%	100%
1B(12)	9	All 7 key benthic risk drivers	100%	100%	100%	100%	100%	100%	100%	100%	100%
1C+(12)	9		100%	100%	100%	100%	100%	100%	100%	100%	100%
2B(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
2C+(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
3B(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
3C+(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
2C+(7.5)	11		100%	100%	100%	100%	100%	100%	100%	100%	100%
3E(7.5)	13		100%	100%	100%	100%	100%	100%	100%	100%	100%

Percent Locations Below CSL[a]

Alternative	Construction Time (years)	COC	Time After Construction (years) 0	5	10	15	20	25	30	35	40
No Action	-	All 7 key benthic risk drivers	70%	nc	nc	nc	nc	nc	nc	nc	nc
1A(12)	9	Mercury	100%	100%	100%	100%	100%	100%	100%	100%	100%
		BEHP	99%	99%	99%	99%	99%	99%	99%	99%	99%
		1,4-DCB	99%	99%	99%	99%	99%	99%	99%	99%	99%
		Total PCBs	99%	99%	99%	99%	99%	100%	100%	100%	100%
		All other key benthic risk drivers	100%	100%	100%	100%	100%	100%	100%	100%	100%
1B(12)	9	All 7 key benthic risk drivers	100%	100%	100%	100%	100%	100%	100%	100%	100%
1C+(12)	9		100%	100%	100%	100%	100%	100%	100%	100%	100%
2B(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
2C+(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
3B(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
3C+(12)	10		100%	100%	100%	100%	100%	100%	100%	100%	100%
2C+(7.5)	11		100%	100%	100%	100%	100%	100%	100%	100%	100%
3E(7.5)	13		100%	100%	100%	100%	100%	100%	100%	100%	100%

Notes:
a. Presented for informational purposes only.

Colored cells indicate achievement of RAO 3, based on at least 98% of surface sediment locations that are predicted to be below the PRGs or CSL.

1. For the purpose of the FS, predicted compliance of RAO 3 PRGs for the key benthic risk drivers over time is approximated by at least 98% of existing surface locations sediment sample locations with key benthic risk driver COC concentrations predicted to be below the PRGs.

2. Point mixing model evaluation was conducted using seven key benthic risk driver COCs (total PCBs, arsenic, mercury, total HPAHs, total LPAHs, BEHP, and 1,4-dichlorobenzene), which serve as a surrogate for the 29 SMS contaminants identified as benthic invertebrate community COCs in the ERA (Windward 2012a). Total PCBs and arsenic are also human health risk drivers.

3. Concentration predictions use the point mixing model evaluation for key benthic risk driver COCs described in Section 5 in MNR areas (under piers and under bridges, 18 locations). The percent of sediment locations below PRGs and CSL is calculated by dividing the predicted number of surface locations exceeding by the number of FS baseline locations (n = 342 locations), which includes existing surface and shallow subsurface (0-2 ft) sediment sample locations in areas exposed to propeller wash.

4. For Alternative 1A(12), surface sediment locations exceeding the PRGs or the CSL at specific times are presented in Appendix J (Figures 7a and 7b) for key benthic risk driver COCs.

5. For the No Action Alternative, the percentage of sediment locations below PRGs and CSL are presented for existing conditions. Point predictions were not calculated for the No Action Alternative based on the expectation that many of these points will remain above the PRGs in the long term.

1,4-DCB – 1,4-dichlorobenzene; BEHP – bis(2-ethylhexyl)phthalate; COC – contaminant of concern; cPAH – carcinogenic polycyclic aromatic hydrocarbon; CSL – cleanup screening level; ERA – ecological risk assessment; FS – Feasibility Study; HPAH – high-molecular-weight polycyclic aromatic hydrocarbon; LPAH – low-molecular-weight polycyclic aromatic hydrocarbon; MNR – monitored natural recovery; nc – not calculated; PRG – preliminary remediation goal; RAO – remedial action objective; SMS - Sediment Management Standards

- None of the alternatives achieve total PCB and dioxin/furan natural background - based PRGs for the human seafood consumption scenario. However, the action alternatives reduce total PCB SWACs between 87% and 92% at year 40, compared to pre-construction conditions.

- **RAO 2 (Table 9-2; Figures 9-1c and 9-2a)**

  All alternatives, except for No Action, are predicted to meet the natural background-based PRG for arsenic of 7 mg/kg dw (based on the UCL95; LDW ROD 2014) at year 0 (immediately after construction completion [9 to 13 years, depending on the alternative]) for site-wide netfishing and clamming areas. All alternatives, including No Action, may meet this RAO 2 PRG in the long term, depending on incoming sediment concentrations (Section 9.15.1.2).

  - The site-wide and clamming area SWACs for arsenic show an increase when comparing years 0 to 5 (after construction completion) due to the impacts from vessel propwash and the predicted concentration of the incoming lateral and upstream material depositing in the EW that is higher than the predicted surface sediment chemistry at year 0 (after construction completion) for this COC. All action alternative SWACs are below the site-wide and clamming area PRG for arsenic (7 mg/kg dw) immediately after construction, and may also maintain the PRG in the long term, depending on incoming sediment concentrations (Section 9.15.1.2).

- **RAO 3 (Table 9-3)**

  - The No Action Alternative is not expected to achieve the PRGs for RAO 3.
  - Alternative 1A(12) is predicted to achieve the RAO 3 PRG for total PCBs of at least 98% of surface sediment locations below the PRGs by year 30 after construction completion (39 years total, including a 9-year construction time). Other key benthic risk driver COCs are predicted to be below their respective PRGs at year 0 (immediately after construction completion [9 years, including construction time]).
  - Alternatives 1B(12) through 3E(7.5) are predicted to achieve this percentage for all key benthic risk driver COCs at year 0 (immediately after construction completion [9 to 13 years, including construction time, depending on the alternative]).

- **RAO 4: (Table 9-1a; Figure 9-1a)**
  - The No Action Alternative is predicted to achieve the total PCB PRGs for the protection of English sole (370 µg/kg dw) and brown rockfish (250 µg/kg dw) by years 10 and 25, respectively.
  - The action alternatives are predicted to achieve site-wide total PCB SWACs below the PRGs for protection of English sole and brown rockfish at year 0 (immediately after construction completion [9 to 13 years, including construction time, depending on the alternative]).

The box model output plotted in Figures 9-1a, 9-1b, and 9-1c (site-wide SWACs) and Figures 9-2a and 9-2b (clamming area SWACs) are based on chemistry from upstream inputs, lateral inputs, post-construction sediment bed replacement values, EW sediments not remediated, and predicted dredge residuals (see Section 5.2 and Appendix B, Part 3A). The impact of input parameters on the results of the long-term effectiveness and recontamination potential evaluations were addressed through bounding and sensitivity analyses described in Sections 5.3.6 and 5.4.6. The results of these evaluations are discussed in Appendix J. Uncertainties of SWAC predictions are summarized in Section 9.15.

In addition, an uncertainty overview was already provided in Section 5.6, including uncertainty introduced into NSRs, initial deposition of EW lateral sources, chemistry assumptions, high-flow scour potential, and mixing depths due to vessel operations.

9.3.2 Reduction in Tissue Concentrations

Table 9-4 presents predictions of total PCB and dioxin/furan concentrations in fish and shellfish tissue based on predicted site-wide total PCB and dioxin/furan SWACs (estimated with the box model, as discussed in Section 9.2.3). As shown in Table 9-4, total PCB tissue concentrations for all species are predicted to decrease over time (starting at year 5) for all of the alternatives. Dioxin/furan tissue concentrations for all species are predicted to slightly increase after construction over years 5 and 10 and then reach steady concentrations for all of the alternatives.

Table 9-4
Predicted Total PCB and Dioxin/Furan Tissue Concentrations

Total PCBs (µg/kg ww)

Alternative	Construction Time (years)	Clams Baseline UCL = 69 Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	140	105	90	81	75	64	61	58	55
1A(12)	9	28	46	45	43	41	32	30	30	29
1B(12)	9	22	27	27	27	26	26	25	25	25
1C+(12)	9	22	26	26	26	26	25	25	25	24
2B(12)	10	22	28	27	27	26	26	25	25	25
2C+(12)	10	22	26	26	26	26	25	25	25	24
3B(12)	10	22	27	27	27	26	26	25	25	25
3C+(12)	10	22	26	26	26	26	25	25	25	24
2C+(7.5)	11	21	26	26	26	25	25	25	24	24
3E(7.5)	13	22	25	25	24	24	24	24	24	24

Alternative	Construction Time (years)	Crab, Whole Body Baseline UCL = 450 Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	650	490	420	390	360	300	290	270	260
1A(12)	9	140	220	220	210	200	150	150	140	140
1B(12)	9	110	130	130	130	130	130	130	130	120
1C+(12)	9	110	130	130	130	130	130	120	120	120
2B(12)	10	110	140	130	130	130	130	130	130	120
2C+(12)	10	110	130	130	130	130	130	120	120	120
3B(12)	10	110	130	130	130	130	130	130	130	120
3C+(12)	10	110	130	130	130	130	130	120	120	120
2C+(7.5)	11	110	130	130	130	130	120	120	120	120
3E(7.5)	13	110	120	120	120	120	120	120	120	120

Alternative	Construction Time (years)	Crab, Edible Meat Baseline UCL = 160 Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	170	130	110	98	91	77	73	70	67
1A(12)	9	35	56	55	52	50	39	37	36	35
1B(12)	9	27	34	34	33	32	32	31	31	31
1C+(12)	9	27	32	32	32	32	31	31	31	30
2B(12)	10	27	34	34	33	32	32	31	31	31
2C+(12)	10	27	32	32	32	32	31	31	31	30
3B(12)	10	28	34	34	33	32	32	31	31	31
3C+(12)	10	28	32	32	32	32	31	31	31	30
2C+(7.5)	11	27	32	32	32	31	31	31	30	30
3E(7.5)	13	27	31	31	30	30	30	30	29	29

Alternative	Construction Time (years)	Pelagic Fish (shiner surfperch) Baseline UCL = 1,600 Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	1800	1350	1140	1020	950	810	760	720	690
1A(12)	9	350	560	550	520	490	400	370	360	350
1B(12)	9	260	330	330	330	320	310	310	300	300
1C+(12)	9	260	320	320	310	310	300	300	300	290
2B(12)	10	260	340	330	330	320	310	310	300	300
2C+(12)	10	260	320	320	310	310	300	300	300	290
3B(12)	10	260	330	330	330	320	310	310	300	300
3C+(12)	10	260	320	320	310	310	300	300	300	290
2C+(7.5)	11	250	310	310	310	300	300	300	290	290
3E(7.5)	13	260	300	300	290	290	290	290	280	280

Alternative	Construction Time (years)	English Sole, whole body Baseline UCL = 4,100 Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	2500	1760	1450	1280	1170	1030	960	900	850
1A(12)	9	400	670	650	600	560	470	440	420	410
1B(12)	9	270	380	380	370	360	350	340	340	330
1C+(12)	9	270	360	360	350	350	340	330	330	320
2B(12)	10	280	390	380	370	360	350	340	340	330
2C+(12)	10	280	360	360	350	350	340	330	330	320
3B(12)	10	280	380	380	370	360	350	340	340	330
3C+(12)	10	280	360	360	350	350	340	330	330	320
2C+(7.5)	11	260	350	350	350	340	330	330	320	320
3E(7.5)	13	270	330	330	320	320	310	310	310	310

Alternative	Construction Time (years)	English Sole, fillet Baseline UCL = 2,400 Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	1400	1030	850	750	680	600	560	520	490
1A(12)	9	230	390	380	350	330	280	260	250	240
1B(12)	9	160	220	220	220	210	210	200	200	190
1C+(12)	9	160	210	210	210	200	200	190	190	190
2B(12)	10	160	230	220	220	210	210	200	200	190
2C+(12)	10	160	210	210	210	200	200	190	190	190
3B(12)	10	160	220	220	220	210	210	200	200	190
3C+(12)	10	160	210	210	210	200	200	190	190	190
2C+(7.5)	11	150	210	210	200	200	190	190	190	190
3E(7.5)	13	160	190	190	190	180	180	180	180	180

Alternative	Construction Time (years)	Brown Rockfish, whole body Baseline UCL = 4,000 Time After Construction (years)								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	3200	2440	2090	1900	1770	1500	1420	1350	1290
1A(12)	9	680	1090	1070	1020	970	760	720	700	680
1B(12)	9	530	660	660	640	630	620	610	610	600
1C+(12)	9	530	630	630	620	610	610	600	590	580
2B(12)	10	530	660	660	640	630	620	610	610	600
2C+(12)	10	530	630	630	620	610	610	600	590	590
3B(12)	10	540	660	660	640	630	620	610	610	600
3C+(12)	10	540	630	630	620	610	610	600	590	590
2C+(7.5)	11	520	620	620	610	610	600	590	590	580
3E(7.5)	13	530	590	590	590	580	580	580	570	570

Table 9-4
Predicted Total PCB and Dioxin/Furan Tissue Concentrations

Dioxins/Furans (ng TEQ/kg ww)

Alternative	Construction Time (years)	Clams Baseline UCL = 0.38								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	ne	ne	ne	ne	ne	ne	ne	ne	ne
1A(12)	9	ne	ne	ne	ne	ne	ne	ne	ne	ne
1B(12)	9	ne	ne	ne	ne	ne	ne	ne	ne	ne
1C+(12)	9	ne	ne	ne	ne	ne	ne	ne	ne	ne
2B(12)	10	ne	ne	ne	ne	ne	ne	ne	ne	ne
2C+(12)	10	ne	ne	ne	ne	ne	ne	ne	ne	ne
3B(12)	10	ne	ne	ne	ne	ne	ne	ne	ne	ne
3C+(12)	10	ne	ne	ne	ne	ne	ne	ne	ne	ne
2C+(7.5)	11	ne	ne	ne	ne	ne	ne	ne	ne	ne
3E(7.5)	13	ne	ne	ne	ne	ne	ne	ne	ne	ne

Alternative	Construction Time (years)	Crab, Whole Body Baseline UCL = 1.3								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	0.98	0.80	0.71	0.66	0.63	0.60	0.58	0.56	0.55
1A(12)	9	0.26	0.46	0.47	0.46	0.45	0.44	0.44	0.43	0.42
1B(12)	9	0.20	0.35	0.37	0.38	0.38	0.39	0.39	0.39	0.39
1C+(12)	9	0.20	0.35	0.37	0.38	0.38	0.39	0.39	0.39	0.39
2B(12)	10	0.20	0.35	0.37	0.37	0.38	0.38	0.39	0.39	0.39
2C+(12)	10	0.20	0.35	0.37	0.38	0.38	0.39	0.39	0.39	0.39
3B(12)	10	0.21	0.34	0.37	0.37	0.38	0.38	0.39	0.39	0.39
3C+(12)	10	0.21	0.34	0.37	0.37	0.38	0.38	0.39	0.39	0.39
2C+(7.5)	11	0.19	0.33	0.36	0.37	0.37	0.37	0.38	0.38	0.38
3E(7.5)	13	0.20	0.33	0.36	0.37	0.38	0.38	0.39	0.39	0.39

Alternative	Construction Time (years)	Crab, Edible Meat Baseline UCL = 0.49								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	0.38	0.31	0.28	0.26	0.24	0.23	0.23	0.22	0.21
1A(12)	9	0.10	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.17
1B(12)	9	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
1C+(12)	9	0.08	0.13	0.15	0.15	0.15	0.15	0.15	0.15	0.15
2B(12)	10	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
2C+(12)	10	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
3B(12)	10	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
3C+(12)	10	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15
2C+(7.5)	11	0.07	0.13	0.14	0.14	0.15	0.15	0.15	0.15	0.15
3E(7.5)	13	0.08	0.13	0.14	0.15	0.15	0.15	0.15	0.15	0.15

Alternative	Construction Time (years)	Pelagic Fish (shiner surfperch) Baseline UCL = 1.4								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	1.1	0.89	0.80	0.74	0.70	0.67	0.65	0.63	0.61
1A(12)	9	0.29	0.51	0.53	0.52	0.50	0.50	0.49	0.48	0.47
1B(12)	9	0.23	0.39	0.41	0.42	0.42	0.43	0.43	0.43	0.43
1C+(12)	9	0.23	0.39	0.42	0.42	0.42	0.43	0.43	0.43	0.44
2B(12)	10	0.23	0.39	0.41	0.42	0.42	0.42	0.43	0.43	0.43
2C+(12)	10	0.23	0.39	0.41	0.42	0.42	0.43	0.43	0.43	0.43
3B(12)	10	0.23	0.38	0.41	0.42	0.42	0.42	0.43	0.43	0.43
3C+(12)	10	0.23	0.38	0.41	0.42	0.42	0.42	0.43	0.43	0.43
2C+(7.5)	11	0.21	0.37	0.40	0.41	0.42	0.42	0.42	0.42	0.42
3E(7.5)	13	0.22	0.37	0.40	0.42	0.42	0.42	0.43	0.43	0.43

Alternative	Construction Time (years)	English Sole, whole body Baseline UCL = 2.8								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	1.49	1.21	1.08	1.00	0.95	0.91	0.88	0.85	0.83
1A(12)	9	0.40	0.69	0.71	0.70	0.68	0.67	0.66	0.65	0.64
1B(12)	9	0.31	0.53	0.56	0.58	0.58	0.58	0.58	0.58	0.58
1C+(12)	9	0.31	0.53	0.57	0.58	0.58	0.58	0.58	0.58	0.59
2B(12)	10	0.31	0.53	0.56	0.57	0.58	0.58	0.58	0.58	0.58
2C+(12)	10	0.31	0.53	0.56	0.58	0.58	0.58	0.58	0.58	0.58
3B(12)	10	0.32	0.52	0.56	0.57	0.58	0.58	0.58	0.58	0.58
3C+(12)	10	0.32	0.52	0.56	0.57	0.58	0.58	0.58	0.58	0.58
2C+(7.5)	11	0.29	0.51	0.55	0.56	0.57	0.57	0.58	0.58	0.58
3E(7.5)	13	0.30	0.51	0.55	0.57	0.58	0.58	0.58	0.58	0.58

Alternative	Construction Time (years)	English Sole, fillet Baseline UCL = 0.79								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	0.64	0.52	0.46	0.43	0.41	0.39	0.38	0.37	0.36
1A(12)	9	0.17	0.30	0.31	0.30	0.29	0.29	0.29	0.28	0.28
1B(12)	9	0.13	0.23	0.24	0.25	0.25	0.25	0.25	0.25	0.25
1C+(12)	9	0.13	0.23	0.24	0.25	0.25	0.25	0.25	0.25	0.26
2B(12)	10	0.13	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.25
2C+(12)	10	0.13	0.23	0.24	0.25	0.25	0.25	0.25	0.25	0.25
3B(12)	10	0.14	0.22	0.24	0.24	0.25	0.25	0.25	0.25	0.25
3C+(12)	10	0.14	0.22	0.24	0.24	0.25	0.25	0.25	0.25	0.25
2C+(7.5)	11	0.12	0.22	0.23	0.24	0.24	0.24	0.25	0.25	0.25
3E(7.5)	13	0.13	0.22	0.23	0.24	0.25	0.25	0.25	0.25	0.25

Alternative	Construction Time (years)	Brown Rockfish, whole body Baseline UCL = 2.8								
		Time After Construction (years)								
		0	5	10	15	20	25	30	35	40
No Action	-	1.97	1.60	1.43	1.33	1.26	1.21	1.17	1.13	1.10
1A(12)	9	0.53	0.92	0.95	0.93	0.91	0.89	0.88	0.87	0.85
1B(12)	9	0.41	0.70	0.74	0.76	0.76	0.78	0.78	0.78	0.78
1C+(12)	9	0.41	0.70	0.75	0.76	0.76	0.78	0.78	0.78	0.79
2B(12)	10	0.41	0.70	0.74	0.75	0.76	0.76	0.78	0.78	0.78
2C+(12)	10	0.41	0.70	0.74	0.76	0.76	0.78	0.78	0.78	0.78
3B(12)	10	0.42	0.68	0.74	0.75	0.76	0.76	0.78	0.78	0.78
3C+(12)	10	0.42	0.68	0.74	0.75	0.76	0.76	0.78	0.78	0.78
2C+(7.5)	11	0.38	0.67	0.72	0.74	0.75	0.75	0.76	0.76	0.76
3E(7.5)	13	0.39	0.67	0.72	0.75	0.76	0.76	0.78	0.78	0.78

Notes:

1. Total PCB tissue concentrations were estimated with the FWM (Anchor QEA and Windward 2014) using the alternative-specific total PCB SWACs in sediment (Table 9-1) and assumed surface water dissolved total PCB concentrations of 0.6 ng/L (except 0.9 ng/L for the No Action Alternative [at years 20 to 40] and for Alternative 1A(12) [years 5 to 20], and 1.2 ng/L for the No Action Alternative [at years 0 to 20]).
2. Dioxin/furan tissue concentrations were estimated with BSAFs (Anchor QEA and Windward 2014) using the alternative-specific dioxin/furan SWACs in sediment (Table 9-1).
3. Baseline tissue concentrations based on UCL95 using actual tissue data collected from the EW, as reported in the HHRA (Windward 2012b). UCL95 is the selected statistic for baseline tissue concentrations consistent with the HHRA. For comparative purposes, year 0 tissue concentrations estimates for the No Action Alternative were calculated using the FWM and BSAFs and total PCB and dioxin/furan SWACs using the FS baseline dataset. Therefore, these differ from the HHRA baseline tissue concentrations. Post-remediation tissue concentrations (UCL95) will be compared to the baseline concentrations (UCL95).
4. No mussel or geoduck data could be predicted for total PCBs or dioxins/furans, nor clam data for dioxins/furans.
5. All tissue concentrations have been rounded to two significant figures.

µg – microgram; BSAF – biota-sediment accumulation factor; EW – East Waterway; FS – Feasibility Study; FWM – food web model; HHRA – human health risk assessment; kg – kilogram; L – liter; ne – not estimated; ng – nanogram; PCB – polychlorinated biphenyl; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence limit on the mean; ww – wet weight

Because the long-term sediment concentrations are relatively similar across Alternatives 1B(12) through 3E(7.5), the predicted total PCB and dioxin/furan tissue concentrations are also similar across these alternatives at any given time. For example, 40 years after the completion of construction, Alternatives 1B(12) through 3E(7.5) are predicted to achieve whole body English sole concentrations of approximately 310 to 330 µg/kg ww for total PCBs and 0.58 ng TEQ/kg ww for dioxins/furans. Predicted total PCB and dioxin/furan tissue concentrations for Alternative 1A(12) are slightly higher for many species than the ones for the other action alternatives during the first 15 years (Table 9-1a).

Uncertainties associated with the tissue concentrations predictions for total PCBs and dioxins/furans are discussed in Section 9.15. Additionally, uncertainties associated with the FWM and the BSAFs are discussed in detail in the SRI (Windward and Anchor QEA 2014).

9.3.3 Reduction in Risks for Human Health

The SWAC predictions discussed above can be used to estimate the human health risks associated with seafood consumption for total PCBs and dioxins/furans (RAO 1) and the risks associated with direct sediment exposure for arsenic (RAO 2). These estimates are used in the FS as milestone metrics for the comparison of alternatives.

9.3.3.1 Risks Associated with Seafood Consumption

Excess cancer risks and non-cancer HQs for total PCBs and dioxins/furans associated with the consumption of resident seafood from the EW were estimated for each of the alternatives at various time points following their implementation. Risks for the other human health seafood consumption risk driver, cPAHs, were largely based on consumption of clams. As noted in Section 3.3.4, it was not possible to predict clam tissue concentrations following remediation.

Excess Cancer Risks

Table 9-5a presents the lifetime individual excess cancer risks for each alternative for the three RME seafood consumption scenarios evaluated in the SRI for total PCBs and dioxins/furans. Calculated risks are shown at various time increments, starting from the end of construction (year 0) and continuing at 5-year intervals through year 40. Color shading in this table indicates the magnitude of the calculated individual excess cancer risk. Figures 9-3a and 9-3b show the predicted post-remedy total PCB and dioxin/furan seafood consumption risks, respectively, for the Adult Tribal RME scenario at years 0, 5, and 40 (after construction completion) for each alternative.

As shown in these figures, the predicted individual excess cancer risks for the Adult Tribal RME seafood consumption scenario are similar for the action alternatives 40 years after construction completion (equal to 2×10^{-4} for total PCBs and 5×10^{-5} for dioxins/furans). The predicted post-remedy individual excess cancer risks for the No Action Alternative for the Adult Tribal RME scenario are slightly higher, equal to 4×10^{-4} for total PCBs and 7×10^{-5} for dioxins/furans.

Individual excess cancer risks are also predicted to be similar in the long term (40 years after construction completion) across alternatives for the Child Tribal RME scenario (risks of 3×10^{-5} to 8×10^{-5} for total PCBs and 8×10^{-6} to 1×10^{-5} for dioxins/furans) and the Adult API RME scenario (risks of 7×10^{-5} to 2×10^{-4} for total PCBs, and 2×10^{-5} to 3×10^{-5} for dioxins/furans).

Total excess cancer risks for the seafood consumption scenarios (i.e., the sum of risks for total PCBs and dioxins/furans[110]) are in the 10^{-4} order of magnitude for the Adult Tribal and API RME scenarios (for the action alternatives) and in the 10^{-5} order of magnitude for the Child Tribal RME scenarios (for Alternatives 1B(12) through 3E(7.5); Table 9-5b). Figure 9-4 shows the predicted total excess cancer risks for the Adult Tribal RME seafood consumption scenario at years 0, 5, and 40 after construction completion for each alternative. The percent risk reduction in total excess cancer risk for the action alternatives is between 70% and 80% for the three RME scenarios.

Non-Cancer Hazard Quotients

Similar to Table 9-5a, Table 9-5c presents the non-cancer HQs for the RME seafood consumption scenarios for total PCBs and dioxins/furans.[111] For total PCBs, HQs for all three

[110] As previously discussed, it was not possible to calculate post-remedy risks for cPAHs (the other seafood consumption scenario risk driver), and thus cPAHs are not included in this sum.

[111] A hazard quotient (HQ) is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. If the HQ is calculated to be equal to or less than 1, then no adverse health effects are expected as a result of exposure. If the HQ is greater than 1, then adverse health effects are possible. The hazard index (HI) is the sum of more than one HQ for multiple substances with similar modes of toxic action (e.g., total PCBs plus dioxins/furans).

RME scenarios are predicted to remain above 1 for all of the alternatives for the HQs calculated based on the immunological/integumentary/neurological endpoints. For the HQs based on the total PCB developmental endpoint, Alternative 1A(12) achieves an HQ of 2 for Adult Tribal, 3 for Child Tribal, and 1 for Adult API RME scenarios 40 years after construction completion. The other action alternatives achieve an HQ of 1 for Adult Tribal, 3 for Child Tribal, and 1 for Adult API RME scenarios 40 years after construction completion. For dioxins/furans, HQs at year 40 are predicted to be equal to or less than 1 for all action alternatives for the Adult Tribal, Child Tribal, and Adult API RME scenarios. Figures 9-5a and 9-5b show the non-cancer HQs associated with residual total PCBs and dioxins/furans at years 0, 5, and 40 after construction completion for each alternative and for the Adult Tribal RME scenario.

In addition to calculating the HQs for the individual risk driver chemicals, the calculation of non-cancer HIs was also considered. Only the HI for the developmental endpoint is presented (Table 9-5d) because no other endpoints include both risk driver chemicals. The HI, which includes the HQ for dioxins/furans and the HQ for total PCBs based on the developmental endpoints, is predicted to be above 1 for all scenarios and alternatives at year 40 after construction completion. It should be noted that total PCBs account for 71% to 88% of this HI sum.

9.3.3.2 Risks Associated with Direct Sediment Exposure

Excess cancer risks for the direct sediment exposure scenarios are presented in Table 9-6.[112] Individual arsenic excess cancer risks for all alternatives are above the 1×10^{-6} threshold for the netfishing and tribal clamming direct contact exposure scenarios. This result was expected because the 1×10^{-6} threshold is below the natural background concentrations for arsenic (see Section 4.4).

At year 0 (immediately after the completion of construction [9 to 13 years, depending on the alternative]), the total excess cancer risk (i.e., excess cancer risks for the direct contact risk driver arsenic) is equal to 1×10^{-5} or less for both the netfishing and tribal clamming scenarios for all alternatives (except the No Action Alternative at year 0 for tribal clamming

[112] Non-cancer HQs were less than one at baseline conditions (year 0), so post-remedy non-cancer HQs were not calculated for the direct sediment exposure RME scenarios because they would also be less than one.

scenario; Table 9-6). Figure 9-6 shows the total risks for both direct sediment exposure scenarios for all alternatives at years 0, 5, and 40 after construction completion.

9.3.4 Reduction in Risks for Ecological Receptors

Total PCBs was identified as a risk driver COC for English sole and brown rockfish based on the tissue residue evaluation. Thus, Table 9-7 presents the post-remedy HQs calculated using FWM-predicted tissue concentrations, based on both of the LOAEL TRVs evaluated in the ERA (LOAEL TRVs of 520 and 2,640 µg/kg ww). Two LOAEL TRVs were presented because of the considerable uncertainty in the study from which the TRVs were derived, as is discussed in both the effects section (Section A.4.2.1.3) and uncertainty section (Section A.6.2.2.2) of the ERA (Windward 2012a). The use of the lower of these TRVs (520 µg/kg ww) likely overestimates risks to these receptors.

The following summarizes the post-remedial HQs:[113]

- **English sole:** HQs are below the threshold of 1.0 using the LOAEL TRV of 2,640 µg/kg ww, with the exception of year 0 for the No Action Alternative. HQs are below the threshold of 1.0 for all years post-construction using LOAEL TRV of 520 µg/kg ww, with the exception of the No Action Alternative and Alternative 1A(12). Alternative 1A(12) is below the threshold of 1.0 LOAEL TRV of 520 µg/kg ww following construction but then is predicted to be slightly above 1.0 (ranging from 1.1 to 1.3) for years 5 through 20 and then is equal to or decreases below 1.0 after this time. The No Action alternative remains above HQ of 1.0 using a LOAEL TRV of 520 µg/kg ww.
- **Brown rockfish:** HQs are below the threshold of 1.0 (with the exception of year 0 for the No Action Alternative) using the LOAEL TRV of 2,640 µg/kg ww. HQs are slightly above 1.0 (ranging from 1.1 to 1.3) for Alternatives 1B(12) through 3E(7.5), with the exception of year 0, when using the LOAEL TRV of 520 µg/kg ww. The HQs for the No Action and Alternative 1A(12) are always greater than 2.5 and 1.3, respectively, for this LOAEL TRV.[114]

[113] The PRGs for RAO 4 are achieved for all action alternatives. HQs are predicted to be above 1.0 for some years due to the influence of water assumptions in the FWM.

[114] HQs predicted to exceed the threshold of 1.0 are due to the water assumptions used in the FWM. Because of uncertainty with these water assumptions, monitoring of fish tissue after remedy completion may be below the lower TRV value.

Table 9-5a
Estimated Individual Excess Cancer Risks for RME Seafood Consumption Scenarios Based on Predicted Long-term Site-wide Total PCB and Dioxin/Furan SWACs

Total PCBs

Alternative	Construction Time (years)	Adult Tribal RME Baseline Risk = 1 x 10^{-3}									Child Tribal RME Baseline Risk = 2 x 10^{-4}									Adult API RME Baseline Risk = 4 x 10^{-4}								
		Time After Construction (years)									Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	1E-03	8E-04	7E-04	6E-04	6E-04	5E-04	5E-04	4E-04	4E-04	2E-04	2E-04	1E-04	1E-04	1E-04	9E-05	9E-05	8E-05	8E-05	4E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04
1A(12)	9	2E-04	3E-04	3E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	4E-05	6E-05	6E-05	6E-05	6E-05	4E-05	4E-05	4E-05	4E-05	8E-05	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	8E-05	8E-05
1B(12)	9	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05
1C+(12)	9	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05
2B(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05
2C+(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05
3B(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05
3C+(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	6E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05
2C+(7.5)	11	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	3E-05	6E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05
3E(7.5)	13	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	6E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05	7E-05

Dioxins/Furans

Alternative	Construction Time (years)	Adult Tribal RME Baseline Risk = 1 x 10^{-4}									Child Tribal RME Baseline Risk = 2 x 10^{-5}									Adult API RME Baseline Risk = 4 x 10^{-5}								
		Time After Construction (years)									Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	1E-04	9E-05	8E-05	8E-05	7E-05	7E-05	7E-05	7E-05	7E-05	2E-05	2E-05	2E-05	1E-05	1E-05	1E-05	1E-05	1E-05	1E-05	4E-05	4E-05	4E-05	4E-05	3E-05	3E-05	3E-05	3E-05	3E-05
1A(12)	9	3E-05	5E-05	6E-05	6E-05	5E-05	5E-05	5E-05	5E-05	5E-05	6E-06	1E-05	1E-05	1E-05	1E-05	1E-05	1E-05	9E-06	9E-06	1E-05	2E-05	3E-05	3E-05	2E-05	2E-05	2E-05	2E-05	2E-05
1B(12)	9	2E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-05	4E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
1C+(12)	9	2E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-05	4E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	9E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
2B(12)	10	2E-05	4E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	4E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
2C+(12)	10	2E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-05	4E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
3B(12)	10	2E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-06	7E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
3C+(12)	10	2E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	5E-06	7E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
2C+(7.5)	11	2E-05	4E-05	4E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	4E-06	7E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05
3E(7.5)	13	2E-05	4E-05	4E-05	4E-05	5E-05	5E-05	5E-05	5E-05	5E-05	4E-06	7E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	1E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05	2E-05

Notes:

1. Baseline human health seafood consumption risks are based on tissue data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. Total PCB excess cancer risks were estimated using tissue concentrations predicted by the FWM (Anchor QEA and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1) and assumed surface water dissolved total PCB concentrations of 0.6 ng/L (except 0.9 ng/L for the No Action Alternative [at years 20 to 40] and for Alternative 1A(12) [years 5 to 20], and 1.2 ng/L for the No Action Alternative [at years 0 to 20]).
3. Dioxin/furan excess cancer risks were estimated using tissue concentrations predicted by BSAFs (Anchor QEA and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1).
4. No mussel or geoduck data could be predicted for total PCBs or dioxins/furans, nor clam data for dioxins/furans. The portion of the diets assigned to these diet items were distributed proportionally to the remaining dietary items.
5. Significant figures are displayed in accordance with the conventions established in the HHRA.
6. Year 0 post-construction risks are estimated considering the likely widespread placement of clean sand (residuals management cover). The increase in risks from year 0 post-construction to year 5 is due to the influences of upstream sediment, lateral loads, vertical mixing of sediment within the waterway, and exchange of sediment between underpier and open-water areas.

10^{-3}
10^{-4}
10^{-5}
10^{-6}

Colored cells indicate estimated excess cancer risk rounded to the nearest order of magnitude.

API – Asian and Pacific Islanders; BSAF – biota-sediment accumulation factor; EW – East Waterway; FWM – food web model; HHRA – human health risk assessment; ng/L – nanogram per liter; PCB – polychlorinated biphenyl; RME – reasonable maximum exposure; SWAC – spatially-weighted average concentration

Table 9-5b

Estimated Total Excess Cancer Risks for RME Seafood Consumption Scenarios Based on Predicted Long-term Site-wide Total PCB and Dioxin/Furan SWACs

Alternative	Construction Time (years)	Adult Tribal RME Baseline Risk = 1 x 10^{-3}									Child Tribal RME Baseline Risk = 2 x 10^{-4}									Adult API RME Baseline Risk = 4 x 10^{-4}								
		Time After Construction (years)									**Time After Construction (years)**									**Time After Construction (years)**								
		0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
No Action	-	1E-03	9E-04	8E-04	7E-04	7E-04	6E-04	5E-04	5E-04	5E-04	2E-04	2E-04	1E-04	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	4E-04	3E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04
1A(12)	9	2E-04	4E-04	4E-04	4E-04	4E-04	3E-04	3E-04	3E-04	3E-04	5E-05	7E-05	7E-05	7E-05	7E-05	5E-05	5E-05	5E-05	5E-05	1E-04	2E-04	2E-04	1E-04	1E-04	1E-04	1E-04	1E-04	1E-04
1B(12)	9	2E-04	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	5E-05	5E-05	5E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	1E-04	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	9E-05
1C+(12)	9	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	1E-04	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05
2B(12)	10	2E-04	3E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	5E-05	5E-05	5E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	9E-05	9E-05
2C+(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	1E-04	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05
3B(12)	10	2E-04	2E-04	3E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	5E-05	5E-05	5E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	1E-04	1E-04	1E-04	1E-04	9E-05	9E-05	9E-05	9E-05
3C+(12)	10	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	1E-04	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05
2C+(7.5)	11	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05
3E(7.5)	13	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	2E-04	3E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	4E-05	7E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05	9E-05

Notes:

1. Baseline human health seafood consumption risks based on tissue data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. Total excess cancer risks include only the risk drivers for the seafood consumption exposure scenario (total PCBs, dioxins/furans). See Table 9-5a for estimated individual excess cancer risks.
3. Significant figures are displayed in accordance with the conventions established in the HHRA.

Legend	
10^{-3}	Colored cells indicate estimated excess cancer risk rounded to the nearest order of magnitude.
10^{-4}	
10^{-5}	

API – Asian and Pacific Islanders; EW – East Waterway; HHRA – human health risk assessment; PCB – polychlorinated biphenyl; RME – reasonable maximum exposure; SWAC – spatially-weighted average concentration

Table 9-5c
Estimated Non-cancer Hazard Quotients for RME Seafood Consumption Scenarios Based on Predicted Long-term Site-wide Total PCB and Dioxin/Furan SWACs

Total PCBs (based on the immunological, integumentary, or neurological endpoints)

Alternative	Construction Time (years)	Adult Tribal RME, Baseline HQ = 27, Time After Construction (years)									Child Tribal RME, Baseline HQ = 58, Time After Construction (years)									Adult API RME, Baseline HQ = 24, Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	27	21	18	16	15	13	12	11	11	58	45	38	34	31	27	25	24	23	24	18	15	14	13	11	10	10	9
1A(12)	9	5	9	9	8	8	6	6	6	5	12	19	18	17	16	13	12	12	12	5	8	7	7	7	5	5	5	5
1B(12)	9	4	5	5	5	5	5	5	5	5	9	11	11	11	11	10	10	10	10	4	5	5	4	4	4	4	4	4
1C+(12)	9	4	5	5	5	5	5	5	5	5	9	11	11	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4
2B(12)	10	4	5	5	5	5	5	5	5	5	9	11	11	11	11	10	10	10	10	4	5	5	4	4	4	4	4	4
2C+(12)	10	4	5	5	5	5	5	5	5	5	9	11	11	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4
3B(12)	10	4	5	5	5	5	5	5	5	5	9	11	11	11	11	10	10	10	10	4	5	5	4	4	4	4	4	4
3C+(12)	10	4	5	5	5	5	5	5	5	5	9	11	11	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4
2C+(7.5)	11	4	5	5	5	5	5	5	5	5	8	10	10	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4
3E(7.5)	13	4	5	5	5	4	4	4	4	4	9	10	10	10	10	10	10	9	9	4	4	4	4	4	4	4	4	4

Total PCBs (based on the developmental endpoint)

Alternative	Construction Time (years)	Adult Tribal RME, Baseline HQ = 8, Time After Construction (years)									Child Tribal RME, Baseline HQ = 17, Time After Construction (years)									Adult API RME, Baseline HQ = 7, Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	8	6	5	5	4	4	3	3	3	17	13	11	10	9	8	7	7	7	7	5	4	4	4	3	3	3	3
1A(12)	9	2	2	2	2	2	2	2	2	2	3	5	5	5	5	4	4	3	3	≤1	2	2	2	2	2	≤1	≤1	≤1
1B(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
1C+(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2B(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2C+(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3B(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	3	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3C+(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	3	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2C+(7.5)	11	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3E(7.5)	13	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	3	3	3	3	3	3	3	3	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1

Dioxins/Furans (based on the developmental endpoint)

Alternative	Construction Time (years)	Adult Tribal RME, Baseline HQ = 1, Time After Construction (years)									Child Tribal RME, Baseline HQ = 2, Time After Construction (years)									Adult API RME, Baseline HQ = 0.9, Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	2	2	2	2	2	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
1A(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
1B(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
1C+(12)	9	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2B(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2C+(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3B(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3C+(12)	10	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
2C+(7.5)	11	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1
3E(7.5)	13	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1	≤1

Notes:

1. Baseline human health seafood consumption hazard quotients based on tissue data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. Total PCB non-cancer hazard quotients were estimated using tissue concentrations predicted by the FWM (Anchor and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1) and assumed surface water dissolved total PCBs concentrations of 0.6 ng/L(except 0.9 ng/L for the No Action Alternative [at years 20 to 40] and for Alternative 1A(12) [years 5 to 20], and 1.2 ng/L for the No Action Alternative [at years 0 to 20]).
3. Dioxin/furan non-cancer hazard quotients were estimated using tissue concentrations predicted by biota-sediment accumulation factors (Anchor QEA and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1).
4. No mussel or geoduck data could be predicted for total PCBs or dioxins/furans, nor clam data for dioxins/furans. The portion of the diets assigned to these diet items were distributed proportionally to the remaining dietary items.
5. All tabulated values are hazard quotients. HQs are rounded following the conventions established in the HHRA (Windward 2012b).

Legend	
HQ >1	Colored cells indicate estimated non-cancer hazard quotient.
HQ ≤1	

API – Asian and Pacific Islanders; EW – East Waterway; FWM – food web model; HHRA – human health risk assessment; HQ – hazard quotient; ng/L – nanogram per liter; PCB – polychlorinated biphenyl; RME – reasonable maximum exposure; SWAC – spatially-weighted average concentration

Table 9-5d

Estimated Non-cancer Developmental Hazard Index for RME Seafood Consumption Scenarios Based on Predicted Long-term Site-wide Total PCB and Dioxin/Furan SWACs

Total PCBs and Dioxins/Furans (based on the developmental endpoint)

Alternative	Construction Time (years)	Adult Tribal RME Baseline HI = 9									Child Tribal RME Baseline HI = 19									Adult API RME Baseline HI = 8								
		Time After Construction (years)									Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	9	7	6	5	5	4	4	4	4	19	15	12	11	10	9	9	8	8	8	6	5	5	4	4	4	3	3
1A(12)	9	2	3	3	3	3	2	2	2	2	4	6	6	6	6	5	5	4	4	2	3	3	3	2	2	2	2	2
1B(12)	9	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
1C+(12)	9	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
2B(12)	10	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
2C+(12)	10	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
3B(12)	10	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
3C+(12)	10	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
2C+(7.5)	11	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2
3E(7.5)	13	≤1	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	≤1	2	2	2	2	2	2	2	2

Notes:

1. Baseline human health seafood consumption hazard index based on tissue data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. The developmental hazard index is equal to the sum of total PCBs and dioxins/furans based on the developmental endpoint. See Table 9-5c for estimated individual non-cancer hazard quotients.
3. All tabulated values are hazard indices. HIs are rounded following the conventions established in the HHRA (Windward 2012b).

HI >1	Colored cells indicate estimated non-cancer hazard index.
HI ≤1	

API – Asian and Pacific Islanders; EW – East Waterway; HI – hazard index; HHRA – human health risk assessment; PCB – polychlorinated biphenyl; RME – reasonable maximum exposure; SWAC – spatially-weighted average concentration

Table 9-6
Estimated Individual Excess Cancer Risks for Direct Contact Based on Predicted Long-term Site-wide and Clamming Arsenic SWACs

Arsenic

Alternative	Construction Time (years)	Site-wide Netfishing Baseline Risk = 3 x 10^{-6}									Tribal Clamming Baseline Risk = 1 x 10^{-5}								
		Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	3E-06	3E-06	3E-06	3E-06	3E-06	3E-06	3E-06	3E-06	3E-06	1E-05	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
1A(12)	9	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
1B(12)	9	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
1C+(12)	9	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
2B(12)	10	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
2C+(12)	10	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
3B(12)	10	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
3C+(12)	10	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
2C+(7.5)	11	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06
3E(7.5)	13	1E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	2E-06	6E-06	6E-06	7E-06	7E-06	7E-06	7E-06	7E-06	7E-06

Notes:

1. Baseline direct contact risks based on data collected from the EW, as reported in the HHRA (Windward 2012b). HHRA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
2. Arsenic risk estimates are based on SWACs for netfishing and tribal clamming areas for each alternative (Table 9-2).
3. Significant figures are displayed in accordance with the conventions established in the HHRA (Windward 2012b).
4. Year 0 post-construction risks are estimated considering the likely widespread placement of clean sand (residuals management cover). The increase in risks from year 0 post-construction to year 5 is due to the influences of upstream sediment, lateral loads, vertical mixing of sediment within the waterway, and exchange of sediment between underpier and open-water areas.

> 1 x 10^{-6}
≤ 1 x 10^{-6}

EW – East Waterway; HHRA – human health risk assessment; SWAC – spatially-weighted average concentration

Table 9-7
Estimated Hazard Quotients for Fish Based on Long-term Site-wide Total PCB SWACs

Using LOAEL TRV of 520 µg/kg ww

Alternative	Construction Time (years)	English Sole Baseline HQ = 7.9									Brown Rockfish Baseline HQ = 0.77 to 12								
		Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	7.9	3.4	2.8	2.5	2.3	2.0	1.8	1.7	1.6	12	4.7	4.0	3.6	3.4	2.9	2.7	2.6	2.5
1A(12)	9	≤ 1.0	1.3	1.2	1.2	1.1	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.3	2.1	2.0	2.0	1.9	1.5	1.4	1.4	1.3
1B(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.1
1C+(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1
2B(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.1
2C+(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1
3B(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.1
3C+(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1
2C+(7.5)	11	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1
3E(7.5)	13	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

Using LOAEL TRV of 2,640 µg/kg ww

Alternative	Construction Time (years)	English Sole Baseline HQ = 1.6									Brown Rockfish Baseline HQ = 0.15 to 2.3								
		Time After Construction (years)									Time After Construction (years)								
		0	5	10	15	20	25	30	35	40	0	5	10	15	20	25	30	35	40
No Action	-	1.6	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	2.3	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
1A(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
1B(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
1C+(12)	9	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
2B(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
2C+(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
3B(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
3C+(12)	10	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
2C+(7.5)	11	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
3E(7.5)	13	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0

Notes:

1. Total PCB hazard quotients were estimated using tissue concentrations predicted by the FWM (Anchor QEA and Windward 2014) with alternative-specific total PCB SWACs in surface sediment (Table 9-1) and assumed surface water dissolved total PCBs concentrations of 0.6 ng/L (except 0.9 ng/L for the No Action Alternative [at years 20 to 40] and for Alternative 1A(12) [years 5 to 20], and 1.2 ng/L for the No Action Alternative [at years 0 to 20]).
2. Baseline ecological risks for fish are based on whole-body tissue data collected from the EW, as reported in the ERA (Windward 2012a). ERA baseline risk estimates are used as year 0 risk estimates for the No Action Alternative.
3. The use of two LOAEL TRVs was done because of the considerable uncertainty in the study from which the TRVs were derived, as is discussed in both the effects section (Section A.4.2.1.3) and uncertainty section (Section A.6.2.2.2) of the ERA (Windward 2012a). The use of the lower of these TRVs (520 µg/kg ww) likely overestimates risks to these receptors.
4. All tabulated values are hazard quotients. HQs are rounded following the conventions established in the ERA (Windward 2012a).

HQ >1.0	Colored cells indicate estimated hazard quotient.
HQ ≤1.0	

µg/kg – microgram per kilogram; ERA – ecological risk assessment; EW - East Waterway; FWM – food web model; HQ – hazard quotient; LOAEL – lowest-observed-adverse-effect level; ng/L – nanogram per liter; PCB – polychlorinated biphenyl; SWAC – spatially-weighted average concentration; TRV – toxicity reference value; ww – wet weight

9.4 No Action Alternative

The No Action Alternative is required as part of the CERCLA process. This alternative provides a basis to compare the relative effectiveness of the other alternatives (see Section 10).

9.4.1 Overall Protection of Human Health and the Environment

No project-specific engineering or institutional controls are assumed for this alternative. Therefore, reduction of contaminant concentrations and risks will occur only to the degree achieved by ongoing natural recovery processes and will be tracked with a site-wide long-term monitoring program.

Predictions for the No Action Alternative have the highest uncertainty because it includes no sediment remediation and therefore, all existing surface and subsurface sediment contamination remain in place.

The No Action Alternative is expected to provide limited protection of human health and the environment, and it does not comprise any provisions for site-wide institutional controls to manage residual risks. A description of PRG achievements for the No Action Alternative is listed below (Table 9-8):

- The No Action Alternative does not achieve the natural background PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO. This alternative is predicted to reduce site-wide total excess cancer risks (for total PCBs and dioxins/furans combined) between 50% and 55% in 40 years, depending on the RME scenario.
- For human health direct contact (RAO 2) for arsenic, this alternative is not predicted to meet the natural background-based RAO 2 PRG for arsenic of 7 mg/kg dw, but may achieve this value in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is not expected to achieve the RAO 3 PRGs because most of the surface sediment locations are predicted to remain above the PRGs for all seven key benthic risk driver COCs; only 22% of the locations are below the PRGs.[115]

[115] Point predictions for compliance with RAO 3 PRGs were not conducted in the long term for the No Action Alternative.

Table 9-8
Model-predicted Times to Achieve Evaluation Metrics for Remedial Action Objectives

Remedial Action Objective and Evaluation Metric	Risk Driver	Time to Achieve Objective or Evaluation Metric (Years from the Start of Construction)[a]									
		Alternative (Construction Time)									
		No Action (-)	1A(12) (9 years)	1B(12) (9 years)	1C+(12) (9 years)	2B(12) (10 years)	2C+(12) (10 years)	3B(12) (10 years)	3C+(12) (10 years)	2C+(7.5) (11 years)	3E(7.5) (13 years)
RAO 1 - Human Health (Seafood Consumption)											
10^{-4} Order of Magnitude Cancer Risk for Adult Tribal RME	Total PCBs	35	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
	Dioxins/Furans	0 (achieves at baseline conditions or start of construction)									
10^{-5} Order of Magnitude Cancer Risk for Child Tribal RME	Total PCBs	Does not achieve.	34	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
	Dioxins/Furans	0 (achieves at baseline conditions or start of construction)									
10^{-4} Order of Magnitude Cancer Risk for Adult API RME	Total PCBs	0 (achieves at baseline conditions or start of construction)									
	Dioxins/Furans	0 (achieves at baseline conditions or start of construction)									
10^{-5} Order of Magnitude Cancer Risk for Adult API RME	Total PCBs	Does not achieve.	Not predicted to achieve.								
	Dioxins/Furans	0 (achieves at baseline conditions or start of construction)									
Natural Background PRGs	Total PCBs	Does not achieve.	Not predicted to achieve.								
	Dioxins/Furans[c]	Does not achieve.	Not predicted to achieve.								
RAO 2 - Human Health (Direct Contact)											
Netfishing (Natural Background Based PRG for As)	Arsenic[d]	Does not achieve.	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
Tribal Clamming (Natural Background Based PRG for As)		Does not achieve.	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
RAO 3 - Ecological Health (Benthic Organisms)											
Benthic (Benthic SCOs)[e]	29 COCs	Not expected to achieve all PRGs.	39[f]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
RAO 4 - Ecological Health (Fish)											
English Sole (SWAC < PRG [370 µg/kg dw])	Total PCBs	10	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]
Brown Rockfish (SWAC < PRG [250 µg/kg dw])		25	9[b]	9[b]	9[b]	10[b]	10[b]	10[b]	10[b]	11[b]	13[b]

Notes:

1. As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15), thus, the upper end of the number of work days in a construction season could increase to around 150 days/season, decreasing the total number of years of construction by 2 years, consistently across the action alternatives. Therefore, times to achieve RAOs could be reduced, compared to those presented in this table.

a. Model-predicted concentrations and associated risks were calculated based on the effective concentration considering bioavailability (i.e., 70% reduction in concentration due to in situ treatment) for the alternatives that include in situ treatment (all alternatives except Alternative 1A(12)) for total PCBs, cPAHs, and dioxins/furans.
b. Evaluation metric is predicted to be achieved by the end of construction.

c. No alternatives are predicted to meet either the natural background concentration for dioxins/furans of 2 ng TEQ/kg dw (calculated based on the UCL95 on the mean, using the OSV Bold Survey [DMMP 2009] dataset [LDW ROD]; EPA 2014).
d. Alternatives 1A(12) through 3E(7.5) are predicted to meet natural background based PRG for arsenic of 7 mg/kg dw (calculated based on the UCL95; LDW ROD 2014) immediately after construction, and may maintain this value in the long term, depending on concentrations in Green River sediments.
e. For FS purposes, achievement of RAO 3 is based on at least 98% of predicted surface sediment locations achieving PRGs for all 29 benthic COCs. This metric acknowledges that the SMS has some flexibility in defining practicability for compliance with the SQS. In addition, the FS recognizes that, given the uncertainty in predictions of future contaminant concentrations based on model- and contaminant-specific assumptions, achievement of 100% compliance with the SQS may not prove to be practicable. Small numbers of SQS point exceedances may represent the potential for isolated minor adverse effects on the benthic community, and those do not necessarily merit further action based on a number of factors (such as sediment toxicity test results), as prescribed in the SMS. Adaptive management measures (e.g., verification monitoring, contingency actions) may become necessary, consistent with the technical feasibility provisions of the SMS, in response to isolated or localized SQS point exceedances. Predictive modeling was not conducted for the No Action Alternative for compliance with RAO 3.
f. Time to achieve RAO 3 PRG based on total PCBs; all other benthic risk driver COCs achieve PRGs immediately after construction completion.

API – Asian Pacific Islander; COC – contaminant of concern; cPAH – carcinogenic polycyclic aromatic hydrocarbon; dw – dry weight; EW – East Waterway; FS – Feasibility Study; LDW – Lower Duwamish Waterway; mg/kg – milligram per kilogram; µg/kg – microgram per kilogram; ng TEQ/kg – nanograms toxic equivalent per kilogram; PCB – polychlorinated biphenyl; PRG – preliminary remediation goal; RAO – remedial action objective; RME – reasonable maximum exposure; ROD – Record Of Decision; SCO – sediment cleanup objective; SMS – Sediment Management Standards; SQS – sediment quality standard; SWAC – spatially-weighted average concentration; TEQ – toxic equivalent; UCL95 – 95% upper confidence level on the mean

- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

The No Action Alternative includes site-wide long-term monitoring to ascertain actual concentrations achieved over time. However, the alternative does not assume any actions (e.g., contingency actions) in response to the monitoring data.

With these considerations, the No Action Alternative does not meet the threshold criterion of overall protection of human health and the environment.

9.4.2 Compliance with ARARs

The No Action Alternative does not comply with ARARs because it is not expected to achieve certain MTCA/SMS numerical cleanup standards (e.g., total PCBs and dioxins/furans for seafood consumption, based on natural background and SMS for benthic organisms) and does not include institutional controls, beyond the existing WDOH seafood consumption advisory, to manage residual risks. In addition, although surface water quality in the EW is expected to improve as a result of upland source control, it will be greatly affected by areas outside of the EW (e.g., Green River, Elliott Bay); therefore, compliance with human health surface water quality criteria for certain contaminants (e.g., total PCBs and arsenic) will not likely occur. The No Action Alternative would also not meet the MTCA requirement (WAC 173-340-440(6)) and similar CERCLA policy for primary reliance on remediation, rather than institutional controls.

9.4.3 Long-term Effectiveness and Permanence

9.4.3.1 Magnitude and Type of Residual Risk

Under the No Action Alternative, ongoing natural recovery processes are predicted to reduce risks over time, but this alternative is not expected to achieve all RAOs.

Endpoints and risk outcomes are described below for the No Action Alternative (achievement of PRGs for each RAO is discussed in Section 9.4.1):

- **RAO 1 (Tables 9-5a through 9-5d)**: The long-term (40-year) residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 4×10^{-4} (Adult Tribal RME), 8×10^{-5} (Child Tribal RME), and 2×10^{-4} (Adult API

RME). Predicted residual excess cancer risks of 7×10^{-5} (Adult Tribal RME), 1×10^{-5} (Child Tribal RME), and 3×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans. The RME seafood consumption non-cancer HQs based on the immunological, integumantary, or neurological endpoints (by year 40) associated with total PCBs are predicted to be above 1 (11 for Adult Tribal, 23 for Child Tribal, and 9 for Adult API). The RME seafood consumption non-cancer HQs based on the developmental endpoint (by year 40) associated with total PCBs are predicted to be above 1 (3 for Adult Tribal, 7 for Child Tribal, and 3 for Adult API). The seafood consumption non-cancer HQs (by year 40) associated with dioxins/furans are predicted to be equal to or below 1 for all three RME scenarios.

- **RAO 2 (Table 9-6)**: The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} (by year 40). Specifically, arsenic is predicted to result in 3×10^{-6} and 7×10^{-6} excess cancer risks by year 40 for netfishing and tribal clamming RME scenarios, respectively.
- **RAO 3 (Table 9-3):** Adverse effects to the benthic community would not be addressed because existing surface sediment locations for all key benthic risk driver COCs exceeding the PRGs will remain, although natural recovery processes may address some but not all COCs.
- **RAO 4 (Table 9-7):** In the long term (by year 40), total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and above 1.0 for both brown rockfish (HQ of 2.5) and English sole (HQ of 1.6) for the LOAEL TRV of 520 µg/kg ww.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place for the No Action Alternative, which would leave existing contaminated sediment above the RALs in place in the EW area. Of the total 146 core stations, 76 and 41 would remain containing subsurface sediment exceeding the CSL and RAL/SQS, respectively.

9.4.3.2 Adequacy and Reliability of Controls

With the exception of the continuation of the existing seafood consumption advisory and site-wide monitoring, no controls are included in this alternative. These controls would not be adequate for managing residual risks in the EW. The No Action Alternative retains the greatest amount of contaminated subsurface sediment (see Section 9.4.3.1) that could be exposed at the surface and that could be difficult to identify and manage into the future. Measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

9.4.4 Reductions in Toxicity, Mobility, or Volume through Treatment

No treatment is included in the No Action Alternative to reduce toxicity, mobility, or volume of contaminated sediments.

9.4.5 Short-term Effectiveness

9.4.5.1 Community and Worker Protection

Since the No Action Alternative assumes that no remedial actions will occur, it would not cause any additional risks due to construction activities to workers or the community beyond minor impacts during monitoring.

9.4.5.2 Environmental Impacts

Environmental impacts associated with implementation of the No Action Alternative are negligible because the only physical activity is monitoring.

9.4.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for the No Action Alternative to achieve each RAO, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2.

For RAO 1, the natural background-based PRGs for total PCBs and dioxins/furans are not achieved by the No Action Alternative within a 40-year period. The No Action Alternative is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 35 and at year 0 (baseline conditions), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME at year 0 (baseline conditions) for dioxins/furans, but does not achieve it for total PCBs

- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (baseline conditions) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (baseline conditions) for dioxins/furans, but does not achieve for total PCBs

The No Action Alternative is not predicted to achieve 7 mg/kg dw for arsenic either site-wide nor in clamming exposure areas; however, this alternative may achieve 7 mg/kg dw in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, this alternative is not expected to achieve the PRGs because no contingency actions are included if the site does not recover through natural recovery processes (only 22% of surface sediment locations are below the PRG for all key benthic risk driver COCs at baseline [at year 0]; long-term predictions were not calculated for this alternative).

The RAO 4 PRGs for the No Action Alternative are predicted to be achieved by year 10 for English sole and by year 25 for brown rockfish.

9.4.6 Implementability

The No Action Alternative is administratively implementable. The only action undertaken is monitoring. Further, because this is the CERCLA No Action Alternative, no contingency actions are assumed to be undertaken in response to monitoring data.

9.4.7 Cost

Only site-wide monitoring costs (assumed for a 20-year period) are associated with the No Action Alternative at an estimated cost of $950,000 (see Appendix E for details).

9.4.8 State, Tribal, and Community Acceptance

The No Action Alternative is unlikely to be acceptable to the state, tribes, and community. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD following the public comment period on EPA's Proposed Plan.

9.5 Alternative 1A(12)

Table 9-9 presents a summary for Alternative 1A(12) including areas, volumes, construction timeframe, and costs.

9.5.1 Overall Protection of Human Health and the Environment

Alternative 1A(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, partial removal and ENR-nav/ENR-nav, ENR-sill (under the West Seattle Bridge and low bridges), and MNR (underpier areas and low bridges). This alternative addresses 108 acres of contaminated sediment through dredging, partial dredging and capping, partial removal and ENR-nav/ENR-nav, and ENR-sill, and has an MNR footprint of 13 acres (Table 9-9). Alternative 1A(12) has an estimated construction period of 9 years, during which the community, workers, and the environment would be affected as described in Section 9.5.5.

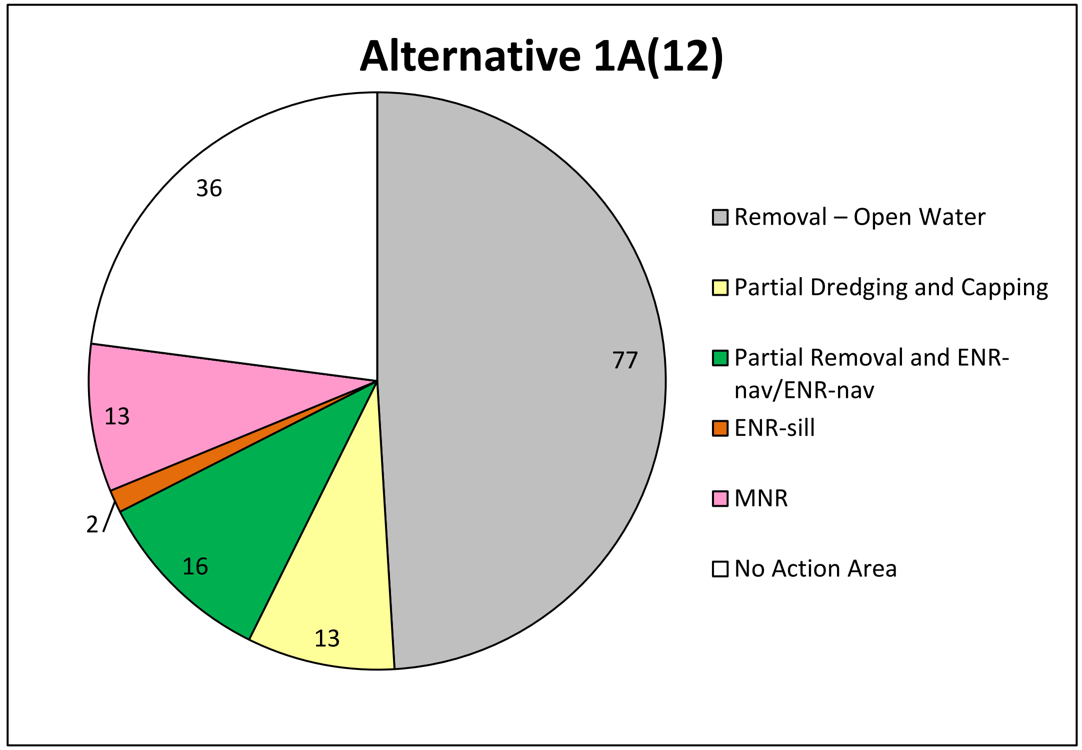
A description of PRG achievements for Alternative 1A(12) is listed below (Table 9-8):

- Alternative 1A(12) does not achieve the natural background-based PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 70% and 75% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRGs immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk

Table 9-9
Alternative 1A(12) Summary

Areas (acres)	
Removal – Open Water	77
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	16
ENR-sill	2
MNR	13
Hydraulic Dredging Followed by In situ Treatment	0
In Situ Treatment	0
No Action Area	36
Volumes (cy)	
Total Removal Volume	810,000
Total Placement Volume	290,000
Construction Timeframe (years)	
Construction Time	9
Costs ($ Million)	
Construction Costs	196
Non-construction Costs	60
Total Costs (rounded)	256



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring and maintenance are required for this alternative, which includes 13 acres of partial dredging and capping, 16 acres of partial removal and ENR-nav/ENR-nav, 2 acres of ENR-sill, and 13 acres of MNR.

Considering the factors described in this section, Alternative 1A(12) achieves the threshold criterion of overall protection of human health and the environment.

9.5.2 Compliance with ARARs

Alternative 1A(12) is expected to comply with ARARs as follows:

- This alternative is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[116] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. For protection of human health for seafood consumption (RAO 1), modeling predicts that Alternative 1A(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW. CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:
  - Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may

[116] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long-term after construction due to incoming sediment concentrations.

take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).

  - SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

- Although surface water quality in the EW is expected to improve as a result of sediment remediation and upland source control, but it will be greatly affected by areas outside of the EW (e.g., Green River, Elliott Bay) and not likely comply with human health surface water quality standards for certain contaminants (e.g., total PCBs and arsenic).

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 1A(12) achieves the threshold criterion of compliance with ARARs.

9.5.3 Long-term Effectiveness and Permanence

9.5.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 1A(12) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to slowly decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 1A(12) (achievement of PRGs for each RAO is discussed in Section 9.5.1):

- **RAO 1 (Tables 9-5a through 9-5d):** Long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 4×10^{-5} (Child Tribal RME), and 8×10^{-5} (Adult API RME) 40 years after completion of construction. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 9×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 12 for Child Tribal, and 5 for Adult API) in the long term (40 years after completion of construction). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be above 1 (2 for Adult Tribal and 3 for Child Tribal), and equal to 1 (for Adult API) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs 40 years after completion of construction associated with dioxins/furans are predicted to be at or below 1 for all three RME scenarios.
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[117]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs (30 years after construction completion; 39 years, including construction time) and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.3 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after completion of construction.

[117] Arsenic natural background concentrations exceed 1 x 10^{-6} excess cancer threshold (see Section 9.3.3.2).

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, with partial removal and ENR-nav/ENR-nav and ENR-sill areas having smaller potential than MNR areas. Based on the approach outlined in Section 9.1.2.1, Table 9-10 evaluates the post-construction potential to increase surface sediment concentrations from exposure of subsurface contamination. Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; no cores greater than CSL and four cores greater than RAL/SQS would remain in areas with partial removal and ENR-nav/ENR-nav; one core greater than CSL and two cores greater than RAL/SQS would remain in areas with ENR-sill; and only one core station with a concentration greater than the RAL/SQS would remain in MNR areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 16 acres in partial removal and ENR-nav/ENR-nav, 2 acres in ENR-sill, and 13 acres in MNR areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed (Section 9.1.2.1). The majority of the sediments are being remediated through removal actions (77 acres), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.5.3.2 Adequacy and Reliability of Controls

Alternative 1A(12) removes 77 acres of contaminated sediment from the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 13 acres of MNR, 16 acres of partial removal and ENR-nav/ENR-nav, and 2 acres of ENR-sill under Alternative 1A(12) will require higher level of monitoring, and may require contingency actions (Table 9-9). MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill are potentially less reliable technologies than others (i.e., dredging, capping), because

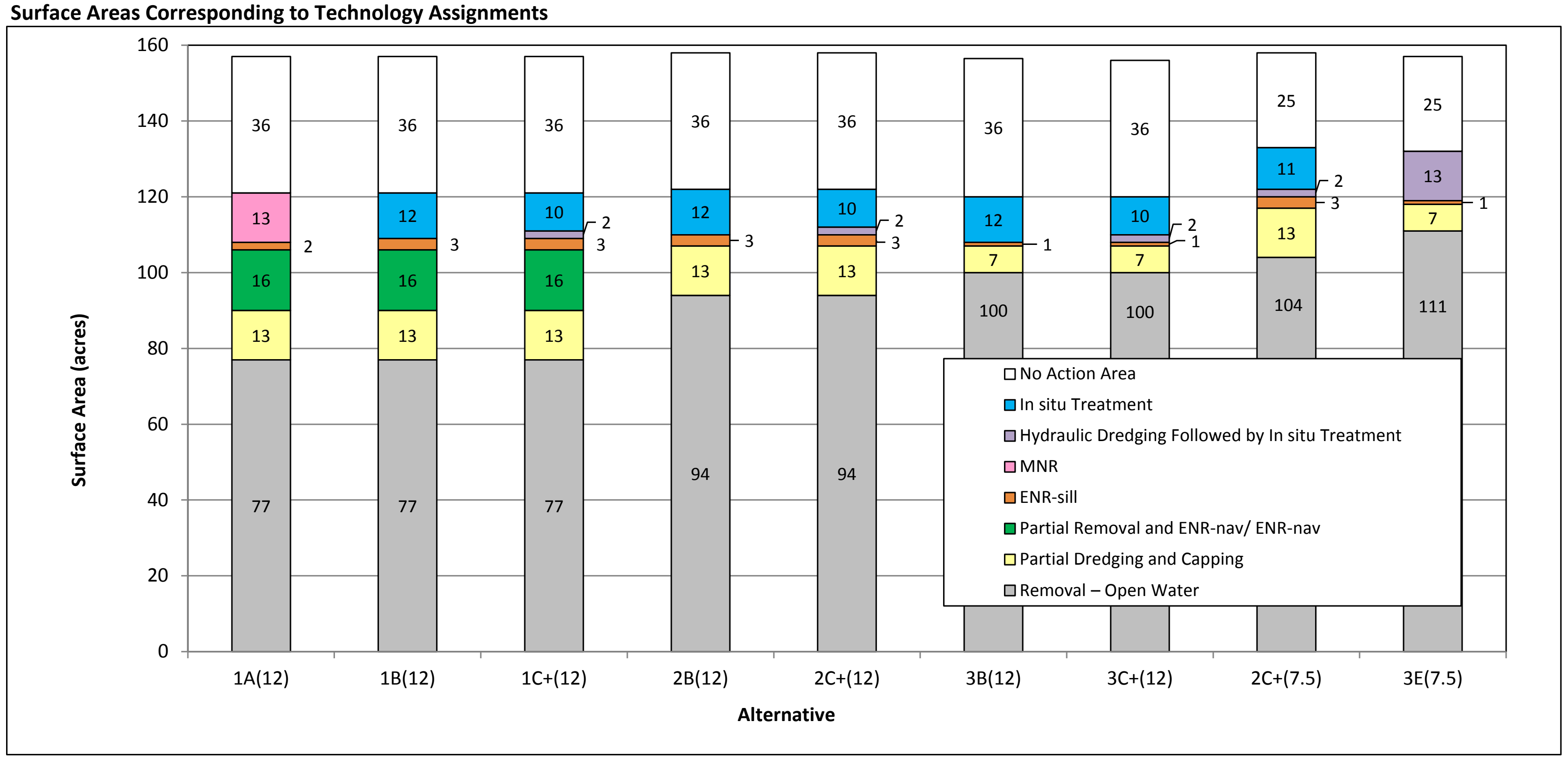
Table 9-10
Post-construction Subsurface Conditions for All Alternatives

Number of Core Stations Remaining with RAL or Benthic SMS Exceedances

Alternative	Core Station Counts Remaining of Total Cores Prior to Remediation															
	Removal	Partial Dredging and Capping		Partial Removal and ENR-nav/ENR-nav		ENR-sill		MNR		Hydraulic Dredging Followed by In situ		In situ Treatment		No Action	
	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS	>CSL	>RAL or >SQS
1A(12)	0 of 88	8 of 31	13 of 31	0 of 8	4 of 8	1 of 2	2 of 2	0 of 1	1 of 1	not used	not used	not used	not used	2 of 16	8 of 16
1B(12)	0 of 88	8 of 31	13 of 31	0 of 8	4 of 8	1 of 2	2 of 2	not used	not used	not used	not used	0 of 1	1 of 1	2 of 16	8 of 16
1C+(12)	0 of 88	8 of 31	13 of 31	0 of 8	4 of 8	1 of 2	2 of 2	not used	not used	0 of 0	0 of 0	0 of 1	1 of 1	2 of 16	8 of 16
2B(12)	0 of 96	8 of 31	13 of 31	not used	not used	1 of 2	2 of 2	not used	not used	not used	not used	0 of 1	1 of 1	2 of 16	8 of 16
2C+(12)	0 of 96	8 of 31	13 of 31	not used	not used	1 of 2	2 of 2	not used	not used	0 of 0	0 of 0	0 of 1	1 of 1	2 of 16	8 of 16
3B(12)	0 of 110	5 of 19	7 of 19	not used	not used	0 of 0	0 of 0	not used	not used	not used	not used	0 of 1	1 of 1	2 of 16	8 of 16
3C+(12)	0 of 110	5 of 19	7 of 19	not used	not used	0 of 0	0 of 0	not used	not used	0 of 0	0 of 0	0 of 1	1 of 1	2 of 16	8 of 16
2C+(7.5)	0 of 98	8 of 31	13 of 31	not used	not used	1 of 2	2 of 2	not used	not used	0 of 0	0 of 0	0 of 1	1 of 1	2 of 14	8 of 14
3E(7.5)	0 of 112	5 of 19	7 of 19	not used	not used	0 of 0	0 of 0	not used	not used	0 of 1	0 of 1	not used	not used	2 of 14	8 of 14

Notes:
1. The total number of core stations is 146; 1 in the underpier areas and 145 in open-water areas.
2. RAL or benthic SMS exceedances are assumed to be the maximum exceedance within the total core depth interval.
3. For the No Action Alternative, of the 146 total core stations, 76 and 41 remain containing subsurface sediment exceeding the CSL and RAL/SQS, respectively.
4. When no core stations were available within a footprint where a specific remedial technology is applied, "0 of 0 cores" was noted.

Surface Areas Corresponding to Technology Assignments



Notes:
1. The total East Waterway Operable Unit surface area is 157 acres.
2. Removal – Open Water includes removal to extent practicable and backfill (Communications Cable Crossing Area) and removal and backfill to existing contours.
3. ENR-nav is enhanced natural recovery applied in the navigation channel and deep-draft berthing areas. It includes partial dredging/ENR-nav and ENR-nav.
4. ENR-sill is enhanced natural recovery applied in the Sill Reach.
5. Two dredge material characterization cores that represent the upper 4-feet of sediment contained concentrations above CSL in the no action area. These areas will be confirmed during remedial design to determine if concentrations are above RALs in surface and shallow subsurface sediment.

CSL – cleanup screening level; ENR – enhanced natural recovery; MNR – monitored natural recovery; n – number of cores; not used – technology not used for the alternative; RAL – remedial action level; SMS – Sediment Management Standards; SQS – sediment quality standard sedimentation rates and contaminant input concentrations are uncertain components of natural recovery. The amount of mixing of open-water sediments with underpier sediments (e.g., sediment exchange) is also a factor that affects natural recovery. Mechanisms such as propeller scour and earthquakes can also more easily expose buried contaminated sediment in MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas. If, as a result of long-term monitoring, MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas indicate unacceptable performance, contingency actions are assumed to be necessary and are included in the cost estimate (see Appendix E). Alternative 1A(12) leaves little contaminated subsurface sediment that could be redistributed in place in MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas (see Section 9.5.3.1 and Table 9-10). While the box model assumes a certain level of exchange of underpier sediment to open-water areas, redistribution or exposure of contaminated sediment in MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 1A(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place in areas remediated with caps, partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR (Section 9.5.3.1). To prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment, the Institutional Controls Plan will include the following, at a minimum:

- Seafood consumption advisories and public outreach and education programs
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users
- Designation of RNAs and other forms of notification and controls for areas with residual contamination to ensure the performance of the remedy

The public outreach and education components are intended to enhance the reliability of the seafood consumption advisories. The advisories themselves are not enforceable and, therefore, have limited reliability.

The combination of monitoring, maintenance, and institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity. As a whole, these activities are intended to allow Alternative 1A(12) to be adaptively managed, as needed, based on new information.

9.5.4 Reductions in Toxicity, Mobility, or Volume through Treatment

No treatment is included in Alternative 1A(12) to reduce toxicity, mobility, or volume of contaminated sediments.

9.5.5 Short-term Effectiveness

9.5.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 9-year construction period for Alternative 1A(12). Fish and shellfish tissue concentrations are predicted to remain elevated throughout the construction period and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (72,400, 125,900, and 12,500, respectively) estimated to support material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, partial removal and ENR-nav/ENR-nav, ENR-sill, backfilling of dredged areas, and RMC (see Appendix I).

Work-related accidents may occur during construction and are proportional to volume of material handled, transportation, and the duration of the remediation activities of Alternative 1A(12) (see Appendix I).

9.5.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations (and also occurs to a lesser degree via man-made erosion events [e.g., propwash scour]). For Alternative 1A(12), it would occur over nine construction seasons. Resuspension of contaminated sediments from dredging will be reduced through the use of BMPs (see Section 7.5.3). Release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) results in concentrations above the RAL. These releases are assumed to be managed through the placement of an RMC layer (9 inches thick, with the goal of achieving a minimum thickness of 6 inches over the area dredged for Alternative 1A(12) [77 acres] and over the interior unremediated areas [19 acres]).[118]

For Alternative 1A(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010; King County 2010).

This alternative consumes regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 290,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-9). The landfill capacity consumed by Alternative 1A(12) is proportional to the volume of dredged material removed and disposed of in the landfill (970,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed from diesel fuel combustion during the remediation activities of Alternative 1A(12) is estimated to be 1.1×10^8 megajoules (MJ; see Appendix I).

[118] RMC is typically used as a contingency action if post-remediation surface sediment concentrations exceed a set threshold; the need, extent, and thickness of the RMC would be determined following post-removal sampling (Section 7.2.6.5).

Estimates of direct and indirect air pollutant emissions associated with Alternative 1A(12) are presented in Appendix I. Implementation of this alternative would result in approximately 16,000 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 5.4 and 5.3 metric tons, respectively), CO (64 metric tons), HCs (19 metric tons), VOCs (20 metric tons), NO_x (130 metric tons), and SO_2 (0.25 metric tons). These emissions are primarily the result of removal, transloading, and transportation of dredged contaminated sediment to the landfill and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees) is approximately 3,784 acres-year (Appendix I).

9.5.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 1A(12) to achieve each RAO, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.

For RAO 1, the natural background-based PRGs for total PCBs and dioxins/furans are not achieved by Alternative 1A(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the net incoming sediment concentration (Section 9.15.1.2). Alternative 1A(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 34 and at year 0 (start of construction), respectively

- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 1A(12) is predicted to achieve 7 mg/kg dw for arsenic by year 9 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs by 39 years for total PCBs and by 9 years (immediately after construction completion) for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 9).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.5.6 Implementability

Alternative 1A(12) has a construction period of 9 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A total of 31 acres would be remediated through the use of MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill in Alternative 1A(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of MNR, partial removal and ENR-nav/ENR-nav, and ENR-sill areas) are assumed as a contingency for Alternative 1A(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.5.7 Cost

The total cost for Alternative 1A(12) is $256 million, which includes estimated construction and non-construction costs of $196 and $60 million, respectively, and accounts for costs for contingency, management, monitoring, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.5.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.6 Alternative 1B(12)

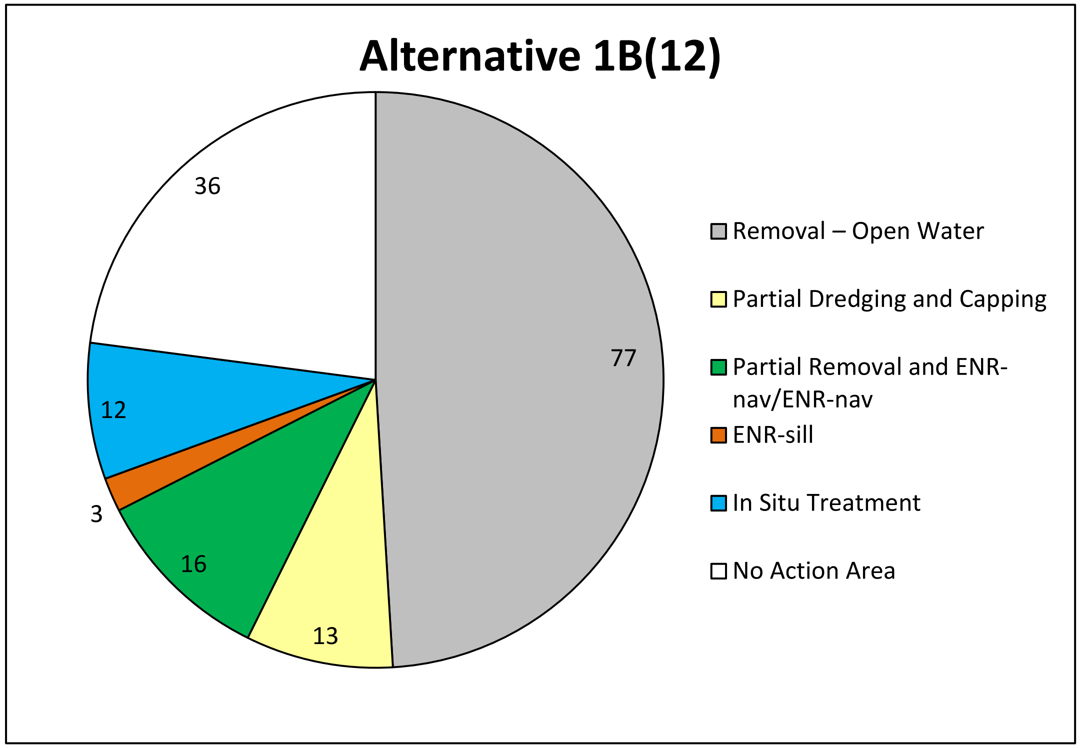
Table 9-11 presents a summary for Alternative 1B(12) including areas, volumes, construction timeframe, and costs.

9.6.1 Overall Protection of Human Health and the Environment

Alternative 1B(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, partial removal and ENR-nav/ENR-nav (in the navigation channel), ENR-sill (under the West Seattle Bridge and low bridges), and in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-11). Alternative 1B(12) has an estimated construction period of 9 years, during which the community, workers, and the environment would be affected as described in Section 9.6.5.

Table 9-11
Alternative 1B(12) Summary

Areas (acres)	
Removal – Open Water	77
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	16
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	0
In Situ Treatment	12
No Action Area	36
Volumes (cy)	
Total Removal Volume	810,000
Total Placement Volume	290,000
Construction Timeframe (years)	
Construction Time	9
Costs ($ Million)	
Construction Costs	202
Non-construction Costs	62
Total Costs (rounded)	264



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

A description of PRG achievements for Alternative 1B(12) is listed below (Table 9-8):

- Alternative 1B(12) does not achieve the natural background-based PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 16 acres of partial removal and ENR-nav/ENR-nav, 3 acres of ENR-sill, and 12 acres of in situ treatment.

Considering the factors described in this section, Alternative 1B(12) achieves the threshold criterion of overall protection of human health and the environment.

9.6.2 Compliance with ARARs

Alternative 1B(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[119] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 1B(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

[119] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction, due to incoming sediment concentrations.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 1B(12) achieves the threshold criterion of compliance with ARARs.

9.6.3 Long-term Effectiveness and Permanence

9.6.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 1B(12) significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 1B(12) (achievement of PRGs for each RAO is discussed in Section 9.6.1):

- **RAO 1 (Tables 9-5a through 9-5d):** Long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins and furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs (40 years after construction completion) associated with dioxins/furans are predicted to be below 1 for all three RME scenarios.

- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[120]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within the partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas. Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; no cores greater than CSL and four cores greater than RAL/SQS would remain in areas with partial removal and ENR-nav/ENR-nav; one greater than CSL and two greater than RAL/SQS would remain in areas with ENR-sill; and only one core station with a concentration greater than the RAL/SQS would remain in in situ treatment areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 16 acres in partial removal and ENR-nav/ENR-nav, 3 acres in ENR-sill, and 12 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (77 acres), which results in a much smaller percentage of the waterway with residual contamination left in place.

[120] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

9.6.3.2 Adequacy and Reliability of Controls

Alternative 1B(12) removes 77 acres of contaminated sediment from the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 16 acres of partial removal and ENR-nav/ENR-nav, 3 acres of ENR-sill, and 12 acres of in situ treatment under Alternative 1B(12) will require a higher level of monitoring, and may require contingency actions (Table 9-11). As described for Alternative 1A(12), partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping), because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms can expose buried contaminated sediment in ENR and in situ treatment areas. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates these areas have unacceptable performance (see Section 9.5.3.2). Alternative 1B(12) leaves contaminated subsurface sediment in place in partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas (see Section 9.6.3.1 and Table 9-10), which could be exposed at the sediment surface or, in the case of in situ treatment areas, be redistributed from underpier areas to open-water areas. While the box model predicts a certain level of exchange of underpier sediment to open-water areas, redistribution or exposure of contaminated sediment in partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 1B(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.6.3.1). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity and to allow Alternative 1B(12) to be adaptively managed, as needed, based on new information.

9.6.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-11).

9.6.5 Short-term Effectiveness

9.6.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 9-year construction period for Alternative 1B(12). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (76,000, 126,200, and 12,500, respectively) estimated to support material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, partial removal and ENR-nav/ENR-nav, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, transportation, and duration of the remediation activities of Alternative 1B(12) see Appendix I).

9.6.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 1B(12) would occur over nine construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 1B(12) (77 acres) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 1B(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010; King County 2010).

This alternative consumes regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 290,000 cy of imported granular material would be used for capping, partial removal and ENR-nav/ENR-nav, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-11). The landfill capacity consumed by Alternative 1B(12) is proportional to the volume of dredged material removed and disposed of in the landfill (970,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed from diesel fuel combustion during the remediation activities of Alternative 1B(12) is estimated to be 1.1×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 1B(12) are presented in Appendix I. Implementation of this alternative would result in approximately 16,000 tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 5.6 and 5.5 metric tons, respectively), CO (67 metric tons), HCs and VOCs (20 and 21 metric tons, respectively), NO_x (140 metric tons), and SO_2 (0.26 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 3,784 acre-years (Appendix I).

9.6.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 1B(12) to achieve each RAO, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[121]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 1B(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 1B(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 1B(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 9 (immediately after construction completion) for both site-wide and clamming exposure areas, and may

[121] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

achieve 7 mg/kg dw in the long term, depending on net incoming sediment concentration (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs by year 9 (immediately after construction completion) for total PCBs and the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 9).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.6.6 Implementability

Alternative 1B(12) has a construction period of 9 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-11). Access to the sediments would be difficult due to the presence of the supporting piles and the low overhead clearance under the pier deck surfaces. As discussed in Section 7.2.7.1, the use of traditional marine-based dredging or barge-mounted placement equipment is precluded due to these access restrictions. The primary in situ treatment technology considered for use in the EW is placement of activated carbon, which is required to be handled as bulk material from a stockpile and placed at a specified amount per surface area on the sediments to be treated. Methods for moving this material into confined places (such as the underpier areas) may be limited to specialized equipment and placement methods (e.g., long-reach conveyors such as

Telebelt™ or hydraulic/pneumatic pumping and placement), but these techniques are expected to be implementable.

A total of 31 acres would be remediated through the use of partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment in Alternative 1B(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas) are assumed as a contingency for Alternative 1B(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.6.7 Cost

The total cost for Alternative 1B(12) is $264 million, which includes estimated construction and non-construction costs of $202 and $62 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.6.8 State, Tribal, and Community Acceptance

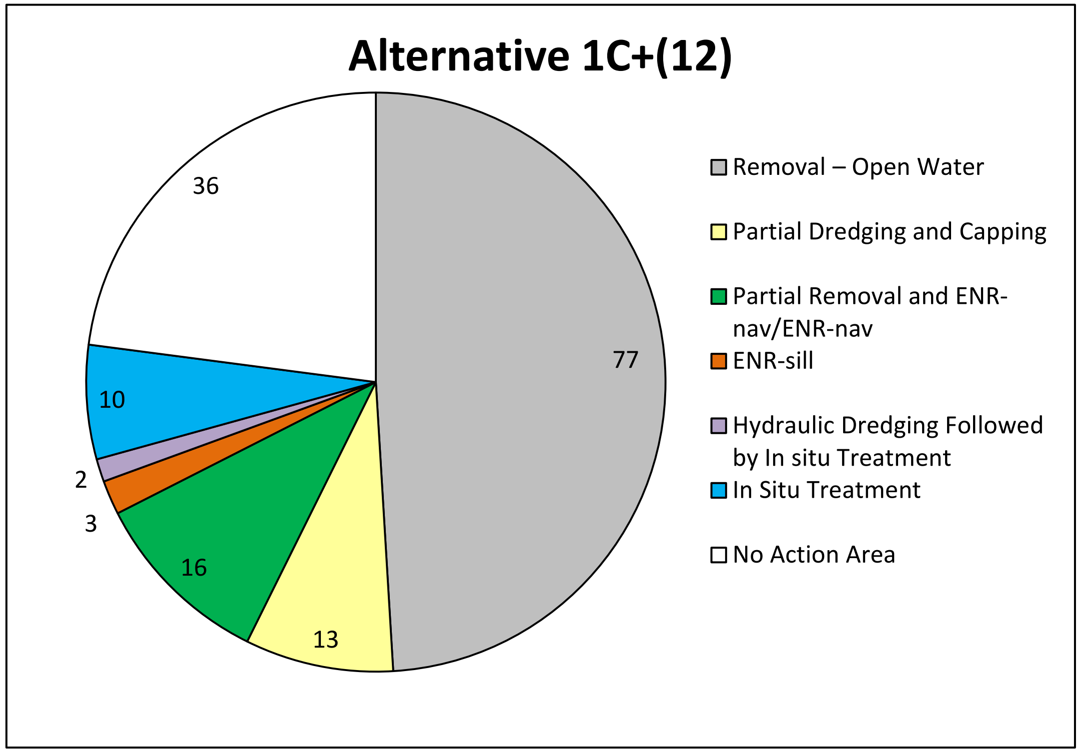
See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.7 Alternative 1C+(12)

Table 9-12 presents a summary for Alternative 1C+(12) including areas, volumes, construction timeframe, and costs.

Table 9-12
Alternative 1C+(12) Summary

Areas (acres)	
Removal – Open Water	77
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	16
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	2
In Situ Treatment	10
No Action Area	36
Volumes (cy)	
Total Removal Volume	820,000
Total Placement Volume	290,000
Construction Timeframe (years)	
Construction Time	9
Costs ($ Million)	
Construction Costs	214
Non-construction Costs	63
Total Costs (rounded)	277



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

9.7.1 Overall Protection of Human Health and the Environment

Alternative 1C+(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, partial removal and ENR-nav/ENR-nav (under navigation channel), ENR-sill (under West Seattle Bridge and low bridges), and in situ treatment and diver-assisted hydraulic dredging followed by in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-12). Alternative 1C+(12) has an estimated construction period of 9 years, during which the community, workers, and the environment would be affected as described in Section 9.7.5.

A description of PRG achievements for Alternative 1C+(12) is listed below (Table 9-8):

- Alternative 1C+(12) does not achieve the natural background-based PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 16 acres of partial removal and ENR-nav/ENR-nav, 3 acres of ENR-sill, 10 acres of in situ treatment, and 2 acres of diver-assisted hydraulic dredging followed by in situ treatment.

Considering the factors described in this section, Alternative 1C+(12) achieves the threshold criterion of overall protection of human health and the environment.

9.7.2 Compliance with ARARs

Alternative 1C+(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[122] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts thatAlternative 1C+(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).

[122] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction, due to incoming sediment concentrations.

- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, Alternative 1C+(12) will not likely comply with human health surface WQS for total PCBs and arsenic.
A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 1C+(12) achieves the threshold criterion of compliance with ARARs.

9.7.3 Long-term Effectiveness and Permanence

9.7.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 1C+(12) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 1C+(12) (achievement of PRGs for each RAO is discussed in Section 9.7.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 9×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API

RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be at or below 1 for all three RME scenarios (40 years after construction completion).

- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[123]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas. Table 9-10 shows that the numbers of core stations with CSL and RAL/SQS exceedances remaining in areas that are partially removed and capped are 8 and 13, respectively; no cores greater than CSL and four cores greater than RAL/SQS would remain in areas with partial removal and ENR-nav/ENR-nav; one greater

[123] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

than CSL and two greater than RAL/SQS would remain in areas with ENR-sill; and only one core station with a concentration greater than the RAL/SQS would remain in in situ treatment areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 16 acres in partial removal and ENR-nav/ENR-nav, 3 acres in ENR-sill, and 10 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (79 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.7.3.2 Adequacy and Reliability of Controls

Alternative 1C+(12) removes 79 acres of contaminated sediment from the EW (including 2 acres with diver-assisted hydraulic dredging in underpier areas) and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 16 acres of partial removal and ENR-nav/ENR-nav, 3 acres of ENR-sill, and 12 acres of in situ treatment under Alternative 1C+(12) will require a higher level of monitoring and may require contingency actions (Table 9-12). As described for Alternative 1A(12), partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment are potentially less reliable as technologies than others (i.e., dredging, capping), because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms that can easily expose buried contaminated sediment in partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates these areas have unacceptable performance (see Section 9.5.3.2). Alternative 1C+(12) leaves contaminated subsurface sediment in place in partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas (see Section 9.7.3.1 and Table 9-10), which could be exposed at the sediment surface or be redistributed from underpier areas to open-water areas. While the box model predicts a certain level of exchange of underpier sediment (including residuals left behind by diver-assisted hydraulic dredging) to open-water areas, redistribution or exposure of contaminated sediment in these areas has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 1C+(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds because (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.7.3.1). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 1C+(12) to be adaptively managed, as needed, based on new information.

9.7.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-12).

9.7.5 Short-term Effectiveness

9.7.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 9-year construction period for Alternative 1C+(12). Fish and shellfish tissue concentrations are predicted to remain elevated for during construction and sometime thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (76,600, 126,200, and 12,600, respectively) estimated to support material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, partial removal and ENR-nav/ENR-nav, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 1C+(12) (see Appendix I). This alternative includes 2 acres of diver-assisted hydraulic dredging in underpier locations over two construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.7.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 1C+(12) would occur over nine construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 1C+(12) (79 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 1C+(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative consumes regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 290,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-12). The landfill capacity consumed by Alternative 1C+(12) is proportional to the volume of dredged material removed and disposed of in the landfill (980,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 3 is estimated to be 1.2×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 1C+(12) are presented in Appendix I. Implementation of this alternative would result in approximately 16,100 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 5.9 and 5.8 metric tons, respectively), CO (73 metric tons), HCs (22 metric tons), VOCs (23 metric tons), NO_x (140 metric tons), and SO_2 (0.27 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 3,808 acres-year (Appendix I).

9.7.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 1C+(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[124]

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[124] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 1C+(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 1C+(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 9 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 1C+(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 9 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs by year 9 (immediately after construction completion) for total PCBs for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 9).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.7.6 Implementability

Alternative 1C+(12) has a construction period of 9 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-12). Anticipated access restrictions and placement methods of activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

Alternative 1C+(12) also includes removal (2 acres; Table 9-12) in underpier areas, followed by in situ treatment. Removing contaminated sediment from underpier locations presents significant engineering and construction difficulties. Diver-assisted hydraulic dredging has the same considerations as standard hydraulic dredging, but with significant additional technical issues and safety concerns, including extremely low production rates, need to treat and manage large volumes of water from sediment slurry, inability to remove consolidated sediment, inability to remove debris, and risk for injury or death. Factors affecting the feasibility of underpier dredging are listed in Sections 7.2.6.3 and 9.1.2.4.

A total of 31 acres would be remediated through the use of partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment in Alternative 1C+(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas) are assumed as a contingency for Alternative 1C+(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.7.7 Cost

The total cost for Alternative 1C+(12) is $277 million, which includes estimated construction and non-construction costs of $214 and $63 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.7.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.8 Alternative 2B(12)

Table 9-13 presents a summary for Alternative 2B(12) including areas, volumes, construction timeframe, and costs.

9.8.1 Overall Protection of Human Health and the Environment

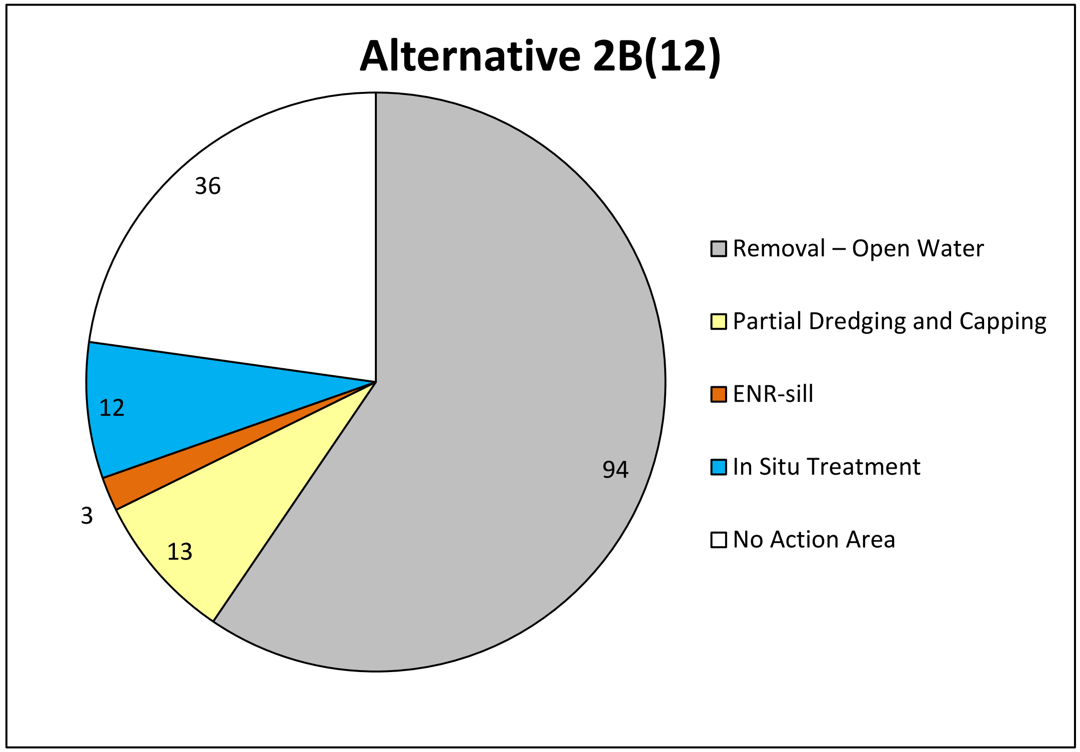
Alternative 2B(12) emphasizes removal and upland disposal followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under the West Seattle Bridge and under low bridges), and in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-13). Alternative 2B(12) has an estimated construction period of 10 years, during which the community, workers, and the environment would be affected as described in Section 9.8.5.

A description of PRG achievements for Alternative 2B(12) is listed below (Table 9-8):

- Alternative 2B(12) does not achieve the natural background-based PRGs for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).

Table 9-13
Alternative 2B(12) Summary

Areas (acres)	
Removal – Open Water	94
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	0
In Situ Treatment	12
No Action Area	36
Volumes (cy)	
Total Removal Volume	900,000
Total Placement Volume	280,000
Construction Timeframe (years)	
Construction Time	10
Costs ($ Million)	
Construction Costs	221
Non-construction Costs	63
Total Costs (rounded)	284



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 12 acres of in situ treatment, and 3 acres of ENR-sill.

Considering the factors described in this section, Alternative 2B(12) achieves the threshold criterion of overall protection of human health and the environment.

9.8.2 Compliance with ARARs

Alternative 2B(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[125] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling

[125] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

predicts that Alternative 2B(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, EPA may issue a ROD Amendment or ESD providing the basis for a TI or other waiver for specified ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 2B(12) achieves the threshold criterion of compliance with ARARs.

9.8.3 Long-term Effectiveness and Permanence

9.8.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 2B(12) significantly would reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 2B(12) (achievement of PRGs for each RAO is discussed in Section 9.8.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[126]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the

[126] Arsenic natural background concentrations exceed 1 x 10^{-6} excess cancer threshold (see Section 9.3.3.2).

PRGs for total PCBs and all key benthic risk driver COCs (immediately after construction completion).

- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas. Table 9-10 shows that the numbers of core stations that would have remaining CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; one core greater than CSL and two cores greater than RAL/SQS would remain in areas with ENR-sill; and one core greater than RAL/SQS would remain in areas with in situ treatment. The corresponding surface areas that would leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 3 acres in ENR-sill, and 12 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (94 acres), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.8.3.2 Adequacy and Reliability of Controls

Alternative 2B(12) removes 94 acres of contaminated sediment from the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

Only 3 acres of ENR-sill, and 12 acres of in situ treatment (in underpier areas) under Alternative 2B(12) will require a higher level of monitoring and may require contingency actions (Table 9-13). As described for Alternative 1A(12), ENR-sill and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping) because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms that can easily expose buried contaminated sediment in ENR and in situ treatment areas. Some uncertainty is also associated with actual reductions in bioavailability as a result of in situ treatment, along with the potential for higher propwash events to redistribute some of the in situ treatment material. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates ENR-sill or in situ treatment areas have unacceptable performance (see Section 9.5.3.2). Alternative 2B(12) leaves contaminated subsurface sediment in place within in situ treatment and ENR-sill areas (see Section 9.8.3.1 and Table 9-10). Therefore, some level of exposure of the sediment surface or redistribution from underpier areas to open-water areas is anticipated affecting long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 2B(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs remains in place (Section 9.8.3.1). The Institutional Controls Plan will include at a minimum the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 2B(12) to be adaptively managed, as needed, based on new information.

9.8.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-13).

9.8.5 Short-term Effectiveness

9.8.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 10-year construction period for Alternative 2B(12). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.
Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (83,900, 121,600, and 12,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, transportation, and duration of the remediation activities of Alternative 2B(12) (see Appendix I).

9.8.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment expected to occur to some degree during dredging operations, which for Alternative 2B(12) would occur over ten construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 2B(12) (94 acres) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 2B(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative consumes regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 280,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-13). The landfill capacity consumed by Alternative 2B(12) is proportional to the volume of dredged material removed and disposed of in the landfill (1,080,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed from diesel fuel combustion during the remediation activities of Alternative 4 is estimated to be 1.2×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 2B(12) are presented in Appendix I. Implementation of this alternative would result in approximately 17,000 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 6.1 and 6.0 metric tons, respectively), CO (72 metric tons), HCs (22 metric tons), VOCs (23 metric tons), NO_x (150 metric tons), and SO_2 (0.27 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,021 acres-year (Appendix I).

9.8.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 2B(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[127]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 2B(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 2B(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 2B(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 10 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 10) for total PCBs and for the other key benthic risk driver COCs.

[127] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 10).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.8.6 Implementability

Alternative 2B(12) has a construction period of 10 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-13). Anticipated access restrictions and placement methods of activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

A total of 15 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 2B(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment would require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed to be likely for Alternative 2B(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.8.7 Cost

The total cost for Alternative 2B(12) is $284 million, which includes estimated construction and non-construction costs of $221 and $63 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.8.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.9 Alternative 2C+(12)

Table 9-14 presents a summary for Alternative 2C+(12) including areas, volumes, construction timeframe, and costs.

9.9.1 Overall Protection of Human Health and the Environment

Alternative 2C+(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under West Seattle Bridge and low bridges), and in situ treatment and diver-assisted hydraulic dredging followed by in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-14).

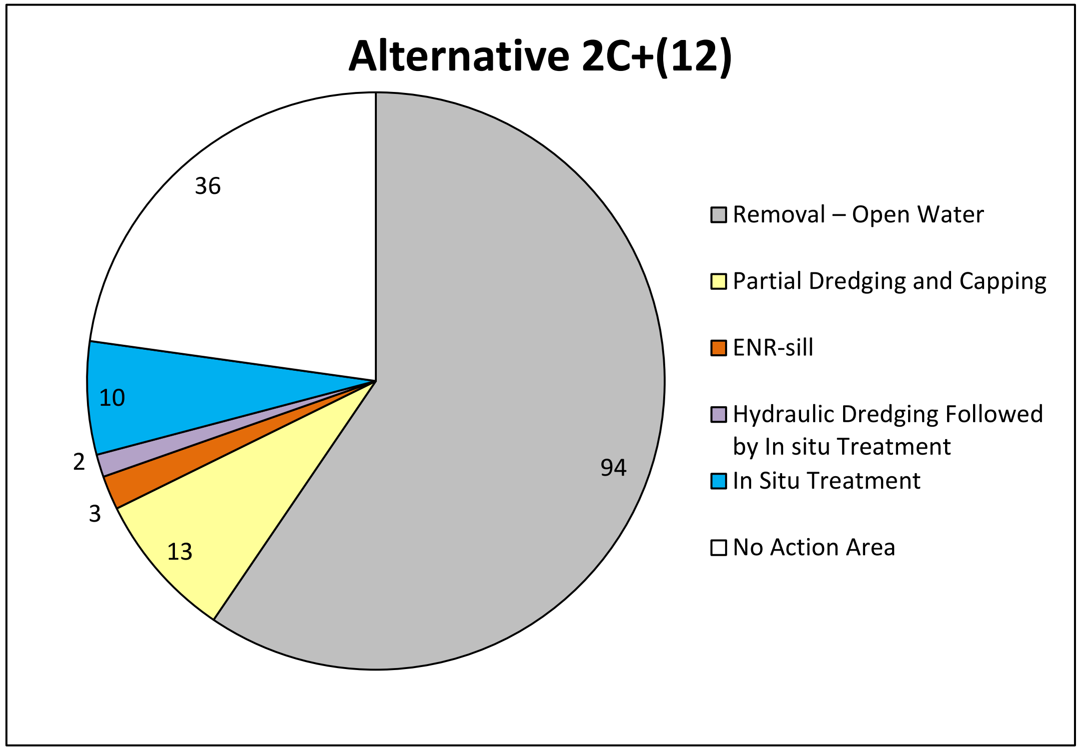
Alternative 2C+(12) has an estimated construction period of 10 years, during which the community, workers, and the environment would be affected as described in Section 9.9.5.

A description of PRG achievements for Alternative 2C+(12) is listed below (Table 9-8):

- Alternative 2C+(12) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).

Table 9-14
Alternative 2C+(12) Summary

Areas (acres)	
Removal – Open Water	94
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	2
In Situ Treatment	10
No Action Area	36
Volumes (cy)	
Total Removal Volume	910,000
Total Placement Volume	280,000
Construction Timeframe (years)	
Construction Time	10
Costs ($ Million)	
Construction Costs	233
Non-construction Costs	64
Total Costs (rounded)	297



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentration. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 3 acres of ENR-sill, 2 acres of diver-assisted hydraulic dredging followed by in situ treatment, and 10 acres of in situ treatment.

Considering the factors described in this section, Alternative 2C+(12) achieves the threshold criterion of overall protection of human health and the environment.

9.9.2 Compliance with ARARs

Alternative 2C+(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[128] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health

[128] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 2C+(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 2C+(12) achieves the threshold criterion of compliance with ARARs.

9.9.3 Long-term Effectiveness and Permanence

9.9.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 2C+(12) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 2C+(12) (achievement of PRGs for each RAO is discussed in Section 9.9.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[129]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface subsurface sediment locations are predicted to be

[129] Arsenic natural background concentrations exceed 1 x 10^{-6} excess cancer threshold (see Section 9.3.3.2).

below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).

- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 μg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 μg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas). Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; one core greater than CSL and two cores greater than RAL/SQS would remain in areas with ENR-sill; and one core greater than RAL/SQS would remain in areas with in situ treatment areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 3 acres in ENR-sill, and 10 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (96 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.9.3.2 Adequacy and Reliability of Controls

Alternative 2C+(12) removes 96 acres (including 2 acres with diver-assisted hydraulic dredging in underpier areas) of contaminated sediment from the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 3 acres of ENR-sill and 12 acres of in situ treatment (in underpier areas) under Alternative 2C+(12) will require more monitoring and may require contingency actions (Table 9-14). As described for Alternative 1A(12), ENR-sill and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping) because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms that can expose buried contaminated sediment in ENR-sill and in situ treatment areas. Some uncertainty is also associated with actual reductions in bioavailability as a result of in situ treatment, along with the potential for higher propwash events to redistribute some of the in situ treatment material. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates ENR-sill and in situ treatment areas have unacceptable performance (see Section 9.5.3.2). Alternative 2C+(12) leaves contaminated subsurface sediment in place in in situ treatment areas and in ENR-sill areas (see Section 9.9.3.1 and Table 9-10), which could be exposed at the sediment surface or be redistributed from underpier areas to open-water areas. The amount of mixing of open-water sediments with underpier sediments (e.g., sediment exchange) is a factor that affects overall natural recovery. While the box model predicts a certain level of exchange of underpier sediment (including residuals left behind by diver-assisted hydraulic dredging) to open-water areas, redistribution or exposure of contaminated sediment in areas with in situ treatment has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 2C+(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.9.3.1). The Institutional Controls Plan will include at a minimum the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 2C+(12) to be adaptively managed, as needed, based on new information.

9.9.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-14).

9.9.5 Short-term Effectiveness

9.9.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 10-year construction period for Alternative 2C+(12). Fish and shellfish tissue concentrations are predicted to remain elevated for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (84,500, 121,500, and 12,900, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 2C+(12) (Appendix I). This alternative includes 2 acres of diver-assisted hydraulic dredging in underpier locations over two construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.9.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 2C+(12) would occur over ten construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 2C+(12) (96 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 2C+(12), the benthic community within approximately 4.1 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by active remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 280,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-14). The landfill capacity consumed by Alternative 2C+(12) is proportional to the volume of dredged material removed and disposed of in the landfill (1,090,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 2C+(12) is estimated to be 1.2×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 2C+(12) are presented in Appendix I. Implementation of this alternative would result in approximately 18,100 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 6.3 and 6.2 metric tons, respectively), CO (78 metric tons), HCs (24 metric tons), VOCs (25 metric tons), NO_x (150 metric tons), and SO_2 (0.29 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,281 acres-year (Appendix I).

9.9.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 2C+(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[130]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 2C+(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 2C+(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 10 years (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

130 As described in Section 9.1.2.3, the total number of years of construction could be reduced by 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

Alternative 2C+(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 10 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 10) for total PCBs and for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 10).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.9.6 Implementability

Alternative 2C+(12) has a construction period of 10 years, remediates 121 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-14). Anticipated access restrictions and placement methods of the activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

Alternative 2C+(12) also includes removal (2 acres; Table 9-14) in conjunction with in situ treatment in underpier areas. Implementability considerations, technical issues, and safety concerns on diver-assisted hydraulic dredging are similar to those described for Alternative 1C+(12) (Section 9.7.6).

A total of 15 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 2C+(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 2C+(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.9.7 Cost

The total cost for Alternative 2C+(12) is $297 million, which includes estimated construction and non-construction costs of $233 and $64 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.9.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.10 Alternative 3B(12)

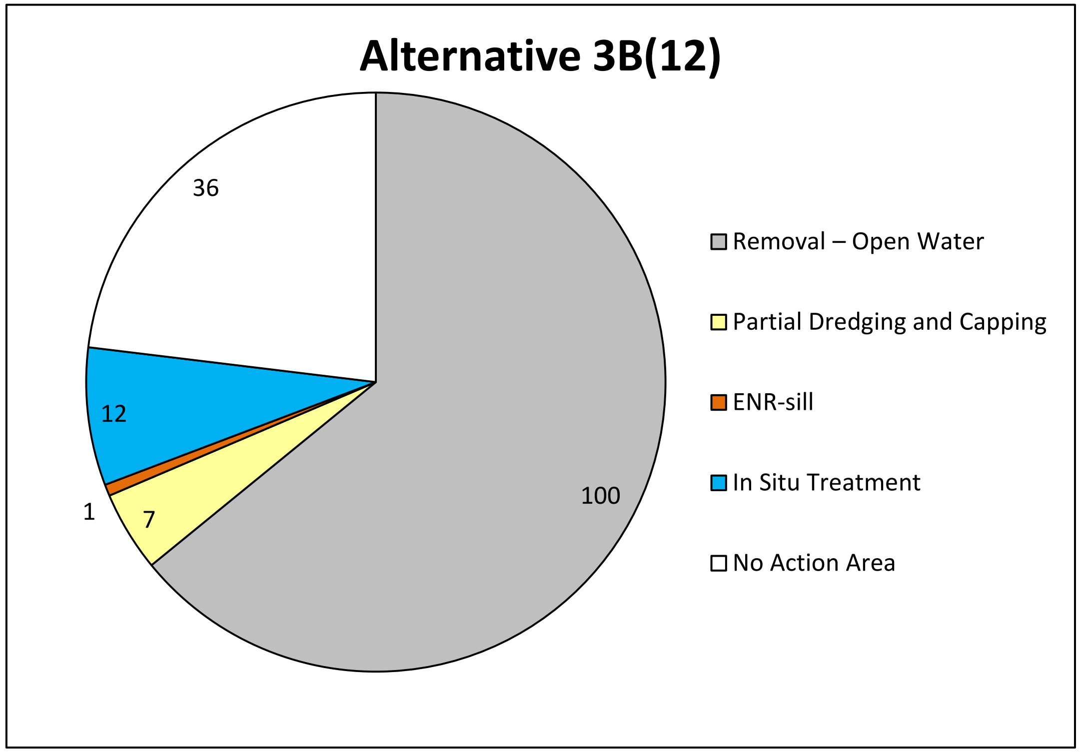
Table 9-15 presents a summary for Alternative 3B(12) including areas, volumes, construction timeframe, and costs.

9.10.1 Overall Protection of Human Health and the Environment

Alternative 3B(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under low bridges), and in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-15). Alternative 3B(12)

Table 9-15
Alternative 3B(12) Summary

Areas (acres)	
Removal – Open Water	100
Partial Dredging and Capping	7
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	1
MNR	0
Hydraulic Dredging Followed by In situ Treatment	0
In Situ Treatment	12
No Action Area	36
Volumes (cy)	
Total Removal Volume	960,000
Total Placement Volume	270,000
Construction Timeframe (years)	
Construction Time	10
Costs ($ Million)	
Construction Costs	233
Non-construction Costs	65
Total Costs (rounded)	298



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

has an estimated construction period of 10 years, during which the community, workers, and the environment would be affected as described in Section 9.10.5.

A description of PRG achievements for Alternative 3B(12) is listed below (Table 9-8):

- Alternative 3B(12) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 7 acres of partial dredging and capping, 1 acres of ENR-sill, and 12 acres of in situ treatment.

Considering the factors described in this section, Alternative 3B(12) achieves the threshold criterion of overall protection of human health and the environment.

9.10.2 Compliance with ARARs

Alternative 3B(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[131] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 3B(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

[131] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 3B(12) achieves the threshold criterion of compliance with ARARs.

9.10.3 Long-term Effectiveness and Permanence

9.10.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 3B(12) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 3B(12) (achievement of PRGs for each RAO is discussed in Section 9.10.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/ furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).

- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[132]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas. Table 9-10 shows that the numbers of core stations with CSL and RAL/SQS exceedances remaining in areas that are partially removed and capped are 5 and 7, respectively; none would remain in ENR-sill areas; and one core greater than RAL/SQS would remain in areas with in situ treatment. The corresponding surface areas that leave some degree of contamination in the subsurface are 7 acres in partial dredging and capping, 1 acre in ENR-sill, and 12 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations would exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (100 acres), which results in a much smaller percentage of the waterway with residual contamination left in place.

[132] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

9.10.3.2 Adequacy and Reliability of Controls

Alternative 3B(12) removes 100 acres of contaminated sediment from the EW and yields a long-term permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals. Areas that undergo partial dredging and capping (7 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

One acre of ENR-sill and 12 acres of in situ treatment under Alternative 3B(12) will require a higher level of monitoring and may require contingency actions (Table 9-15). As described for Alternative 1A(12), ENR-sill and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping), because of several uncertain components of natural recovery and other mechanisms that can easily expose buried contaminated sediment in ENR and in situ treatment areas. Some uncertainty is also associated with actual reductions in bioavailability as a result of in situ treatment, along with the potential for higher propwash events to redistribute some of the in situ treatment material. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates these areas have unacceptable performance (see Section 9.5.3.2). Alternative 3B(12) only leaves contaminated subsurface sediment in place in in situ treatment areas (see Section 9.10.3.1 and Table 9-10). Therefore, some level of exposure of the sediment surface or redistribution from underpier areas to open-water areas is anticipated.

Alternative 3B(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.10.3.1). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls, would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 3B(12) to be adaptively managed, as needed, based on new information.

9.10.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-15).

9.10.5 Short-term Effectiveness

9.10.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 10-year construction period for Alternative 3B(12). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (88,600, 114,500, and 12,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, transportation, and duration of the remediation activities of Alternative 3B(12)(see Appendix I).

9.10.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment expected to occur to some degree during dredging operations, which for Alternative 3B(12) would occur over ten construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 3B(12) (100 acres) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 3B(12), the benthic community within approximately 5.8 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by active remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 270,000 cy of imported granular material is used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-15). The landfill capacity consumed by Alternative 3B(12) is proportional to the volume of dredged material removed and disposed of in the landfill (1,150,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal and electrical energy consumed from diesel fuel combustion during the remediation activities of Alternative 3B(12) are estimated to be 1.3×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 3B(12) are presented in Appendix I. Implementation of this alternative would result in approximately 18,000 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 6.4 and 6.3 metric tons, respectively), CO (77 metric tons), HCs (23 metric tons), VOCs (24 metric tons), NO_x (160 metric tons), and SO_2 (0.29 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,257 acres-year (Appendix I).

9.10.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 3B(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[133]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 3B(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 3B(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 3B(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 10 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

[133] As described in Section 9.1.2.3, the total number of years of construction could be reduced by 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 10) for total PCBs and for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 10).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, uncertain (see Section 9.15).

9.10.6 Implementability

Alternative 3B(12) has a construction period of 10 years, remediates 121 acres, and is administratively implementable. An additional technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-15). Anticipated access restrictions and placement methods of activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

A total of 13 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 3B(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 3B(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.10.7 Cost

The total cost for Alternative 3B(12) is $298 million, which includes estimated construction and non-construction costs of $233 and $65 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.10.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.11 Alternative 3C+(12)

Table 9-16 presents a summary for Alternative 3C+(12) including areas, volumes, construction timeframe, and costs.

9.11.1 Overall Protection of Human Health and the Environment

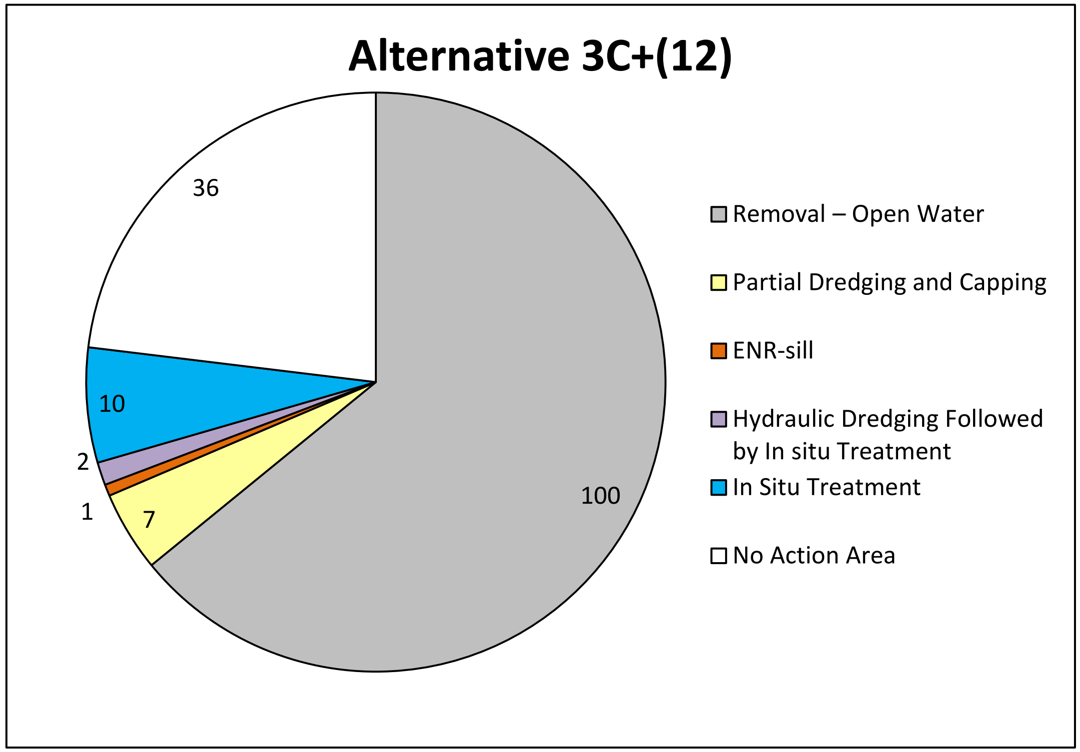
Alternative 3C+(12) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under low bridges), diver-assisted hydraulic dredging followed by in situ treatment, and in situ treatment (underpier areas). This alternative addresses 121 acres of contaminated sediment through these remedial technologies (Table 9-16). Alternative 3C+(12) has an estimated construction period of 10 years, during which the community, workers, and the environment would be affected as described in Section 9.11.5.

A description of PRG achievements for Alternative 3C+(12) is listed below (Table 9-8):

- Alternative 3C+(12) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Table 9-16
Alternative 3C+(12) Summary

Areas (acres)	
Removal – Open Water	100
Partial Dredging and Capping	7
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	1
MNR	0
Hydraulic Dredging Followed by In situ Treatment	2
In Situ Treatment	10
No Action Area	36
Volumes (cy)	
Total Removal Volume	960,000
Total Placement Volume	270,000
Construction Timeframe (years)	
Construction Time	10
Costs ($ Million)	
Construction Costs	244
Non-construction Costs	66
Total Costs (rounded)	310



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 7 acres of partial dredging and capping, 1 acres of ENR-sill, 2 acres of diver-assisted hydraulic dredging followed by in situ treatment, and 10 acres of in situ treatment.

Considering the factors described in this section, Alternative 3C+(12) achieves the threshold criterion of overall protection of human health and the environment.

9.11.2 Compliance with ARARs

Alternative 3C+(12) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[134] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 3C+(12) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain

[134] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).

- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.
A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 3C+(12) achieves the threshold criterion of compliance with ARARs.

9.11.3 Long-term Effectiveness and Permanence

9.11.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 3C+(12) significantly would reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 3C+(12) (achievement of PRGs for each RAO is discussed in Section 9.11.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[135]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside

[135] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas). Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 5 and 7, respectively; none would remain in ENR-sill areas; and one core greater than RAL/SQS would remain in areas with in situ treatment. The corresponding surface areas that leave some degree of contamination in the subsurface are 7 acres in partial dredging and capping, 1 acre in ENR-sill, and 10 acres in in situ treatment areas. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (102 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.11.3.2 Adequacy and Reliability of Controls

Alternative 3C+(12) removes 102 acres (including 2 acres with diver-assisted hydraulic dredging in underpier areas) of contaminated sediment from the open-water and underpier areas of the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (7 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

The 12 acres of in situ treatment (in underpier areas) and 1 acre of ENR-sill (under low bridges) under Alternative 3C+(12) will require a higher level of monitoring and may require contingency actions (Table 9-16). As described for Alternative 1A(12), ENR-sill and in situ treatment are potentially less reliable technologies than others (i.e., dredging, capping) because: a) sedimentation rates and contaminant input concentrations are uncertain components of natural recovery; and b) other mechanisms that can expose buried contaminated sediment in ENR-sill and in situ treatment areas. Some uncertainty is also associated with actual reductions in bioavailability as a result of in situ treatment, along with the potential for higher propwash events to redistribute some of the in situ treatment material. Therefore, contingency actions are included in the cost estimate if long-term monitoring indicates ENR-sill and in situ treatment areas have unacceptable performance (see Section 9.5.3.2). Alternative 3C+(12) only leaves contaminated subsurface sediment in place in in situ treatment areas (see Section 9.11.3.1 and Table 9-10) that could be exposed at the sediment surface or be redistributed from underpier areas to open-water areas. The amount of mixing of open-water sediments with underpier sediments (e.g., sediment exchange) is a factor that affects overall natural recovery. While the box model predicts a certain level of exchange of underpier sediment (including residuals left behind by diver-assisted hydraulic dredging) to open-water areas, redistribution or exposure of contaminated sediment in areas with in situ treatment has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 3C+(12) requires an Institutional Controls Plan because: a) the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary); and b) subsurface sediment with COC concentrations above levels needed to achieve RAOs would remain in place (Section 9.11.3.1). The Institutional Controls Plan will include at a minimum the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 3C+(12) to be adaptively managed, as needed, based on new information.

9.11.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 12 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-16).

9.11.5 Short-term Effectiveness

9.11.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 10-year construction period for Alternative 3C+(12). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (89,200, 114,400, and 12,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 3C+(12) (Appendix I). This alternative includes 2 acres of diver-assisted hydraulic dredging in underpier locations over two construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.11.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment expected to occur to some degree during dredging operations, which for Alternative 3C+(12) would occur over ten construction seasons. The use of BMPs for reducing, the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 3C+(12) (102 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (19 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 3C+(12), the benthic community within approximately 5.8 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 270,000 cy of imported granular material would be used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-16). The landfill capacity consumed by Alternative 3C+(12) is proportional to the volume of dredged material removed and disposed of in the landfill (1,150,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal and electrical energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 3C+(12) are estimated to be 1.3×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 3C+(12) are presented in Appendix I. Implementation of this alternative would result in approximately 18,100 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 6.6 and 6.5 metric tons, respectively), CO (83 metric tons), HCs (25 metric tons), VOCs (26 metric tons), NO_x (160 metric tons), and SO_2 (0.3 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,281 acres-year (Appendix I).

9.11.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 3C+(12) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[136]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 3C+(12) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 3C+(12) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 10 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 3C+(12) is also predicted to achieve 7 mg/kg dw for arsenic by year 10 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

[136] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 3, PRGs are predicted to achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 10) for total PCBs and for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 10).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.11.6 Implementability

Alternative 3C+(12) has a construction period of 10 years, remediates 121 acres, and is administratively implementable. An additional technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (12 acres; Table 9-16). Anticipated access restrictions and placement methods of the activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

Alternative 3C+(12) also includes limited removal (2 acres; Table 9-16) in conjunction with in situ treatment in underpier areas. Implementability considerations, technical issues, and safety concerns on diver-assisted hydraulic dredging are similar to those described for Alternative 1C+(12) (Section 9.7.6).

A total of 13 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 3C+(12); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 3C+(12) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.11.7 Cost

The total cost for Alternative 3C+(12) is $310 million, which includes estimated construction and non-construction costs of $244 and $66 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.11.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.12 Alternative 2C+(7.5)

Table 9-17 presents a summary for Alternative 2C+(7.5) including areas, volumes, construction timeframe, and costs.

9.12.1 Overall Protection of Human Health and the Environment

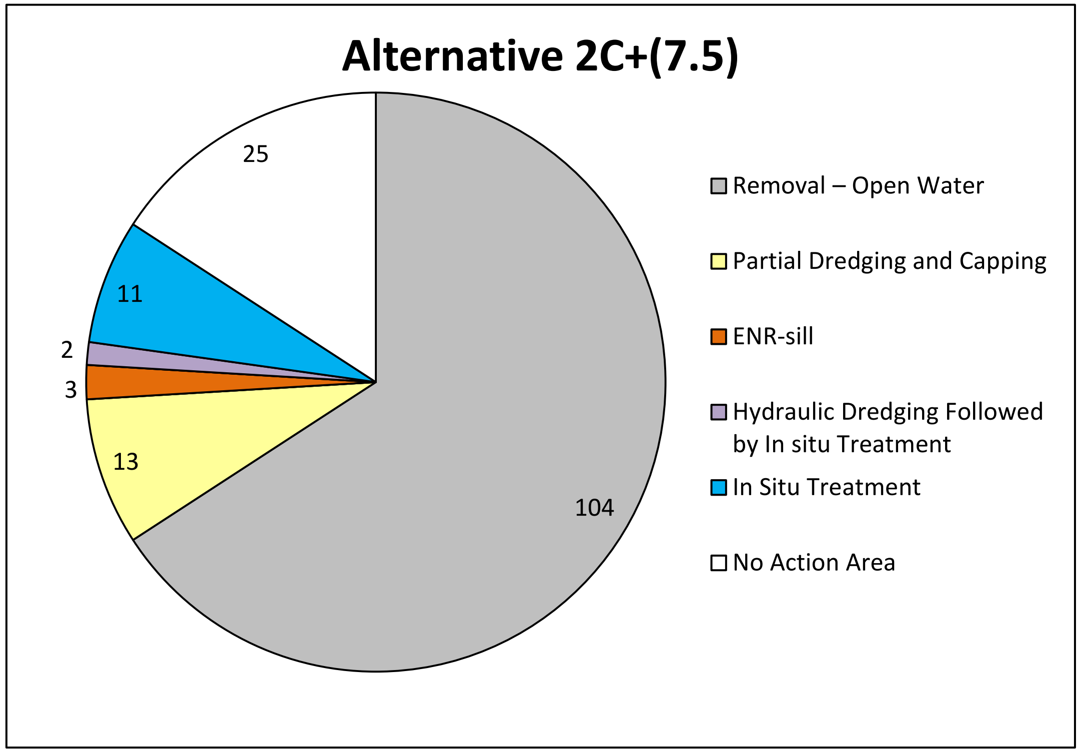
Alternative 2C+(7.5) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under low bridges), diver-assisted hydraulic dredging followed by in situ treatment, and in situ treatment (underpier areas). This alternative addresses 132 acres of contaminated sediment through these remedial technologies (Table 9-17). Alternative 2C+(7.5) has an estimated construction period of 11 years, during which the community, workers, and the environment would be affected as described in Section 9.12.5.

A description of PRG achievements for Alternative 2C+(7.5) is listed below (Table 9-8):

- Alternative 2C+(7.5) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).

Table 9-17
Alternative 2C+(7.5) Summary

Areas (acres)	
Removal – Open Water	104
Partial Dredging and Capping	13
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	3
MNR	0
Hydraulic Dredging Followed by In situ Treatment	2
In Situ Treatment	11
No Action Area	25
Volumes (cy)	
Total Removal Volume	1,010,000
Total Placement Volume	290,000
Construction Timeframe (years)	
Construction Time	11
Costs ($ Million)	
Construction Costs	257
Non-construction Costs	69
Total Costs (rounded)	326



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).
- This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 13 acres of partial dredging and capping, 3 acres of ENR-sill, 2 acres of diver-assisted hydraulic dredging followed by in situ treatment, and 11 acres of in situ treatment.

Considering the factors described in this section, Alternative 2C+(7.5) achieves the threshold criterion of overall protection of human health and the environment.

9.12.2 Compliance with ARARs

Alternative 2C+(7.5) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[137] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health

[137] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 2C+(7.5) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs, such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 2C+(7.5) achieves the threshold criterion of compliance with ARARs.

9.12.3 Long-term Effectiveness and Permanence

9.12.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 2C+(7.5) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a) and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 2C+(7.5) (achievement of PRGs for each RAO is discussed in Section 9.12.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (5 for Adult Tribal, 10 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).
- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[138]

[138] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas. Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 8 and 13, respectively; one greater than CSL and two greater than RAL/SQS would remain in ENR-sill areas; and one exceeding the RAL/SQS would remain in in situ treatment areas. The corresponding surface areas that leave some degree of contamination in the subsurface are 13 acres in partial dredging and capping, 3 acres in ENR-sill, and 11 acres in in situ treatment. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (106 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.12.3.2 Adequacy and Reliability of Controls

Alternative 2C+(7.5) removes 106 acres (including 2 acres with diver-assisted hydraulic dredging in underpier areas) of contaminated sediment from the open-water and underpier areas of the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (13 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

Only 3 acres of ENR-sill (under low bridges) and 13 acres of in situ treatment (underpier areas) under Alternative 2C+(7.5) will require a higher level of monitoring and may require contingency actions (Table 9-17). However, this alternative only leaves contaminated subsurface sediment above the CSL in place in ENR-sill areas (see Section 9.12.3.1 and Table 9-17) that could expose at the sediment surface or be redistributed from underpier areas to open-water areas. The amount of mixing of open-water sediments with underpier sediments (e.g., sediment exchange) is a factor that affects overall natural recovery. While the box model predicts a certain level of exchange of underpier sediment (including residuals left behind by diver-assisted hydraulic dredging) to open-water areas, redistribution or exposure of contaminated sediment in areas with in situ treatment has the potential to affect long-term SWACs. Additional measures needed to ensure adequate monitoring and management for these areas are discussed in Section 9.1.2.1.

Alternative 2C+(7.5) requires an Institutional Controls Plan because the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls, would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 2C+(7.5) to be adaptively managed, as needed, based on new information.

9.12.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 13 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-17).

9.12.5 Short-term Effectiveness

9.12.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 11-year construction period for Alternative 2C+(7.5). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (94,000, 125,600, and 13,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 2C+(7.5) (Appendix I). This alternative includes 2 acres of diver-assisted hydraulic dredging in underpier locations over two construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.12.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 2C+(7.5) would occur over 11 construction seasons. The use of BMPs for reducing, the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 2C+(7.5) (106 acres, including 2 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (15 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 2C+(7.5), the benthic community within approximately 4.7 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by active remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 290,000 cy of imported granular material is used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-17). The landfill capacity consumed by Alternative 2C+(7.5) is proportional to the volume of dredged material removed and disposed of in the landfill (1,210,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal and electrical energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 2C+(7.5) are estimated to be 1.3×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 2C+(7.5) are presented in Appendix I. Implementation of this alternative would result in approximately 19,100 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 7.0 and 6.8 metric tons, respectively), CO (85 metric tons), HCs (26 metric tons), VOCs (27 metric tons), NO_x (170 metric tons), and SO_2 (0.31 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 4,518 acres-year (Appendix I).

9.12.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 2C+(7.5) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[139]

For RAO 1, the natural background based PRGs for total PCB and dioxins/furans are not achieved by Alternative 2C+(7.5) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 2C+(7.5) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 11 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-5} order of magnitude excess cancer risk for the Child Tribal RME by year 11 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 2C+(7.5) is also predicted to achieve 7 mg/kg dw for arsenic by year 11 (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

[139] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 11) for total PCBs and for the other key benthic risk driver COCs.

The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 11).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.12.6 Implementability

Alternative 2C+(7.5) has a construction period of 11 years, remediates 132 acres, and is administratively implementable. Additional technical or administrative complexity is associated with reauthorization of the federal navigation channel in the Shallow Main Body – South Reach from -34 feet MLLW to -30 feet MLLW to accommodate partial dredging and capping in that area. Actual authorized depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process.

A technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (13 acres; Table 9-17). Anticipated access restrictions and placement methods of the activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

Alternative 2C+(7.5) also includes removal (2 acres; Table 9-17) in conjunction with in situ treatment in underpier areas. Implementability considerations, technical issues, and safety concerns on diver-assisted hydraulic dredging are similar to those described for Alternative 1C+(12) (Section 9.7.6).

A total of 16 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 2C+(7.5); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 2C+(7.5) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

9.12.7 Cost

The total cost for Alternative 2C+(7.5) is $326 million, which includes estimated construction and non-construction costs of $257 and $69 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.12.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.13 Alternative 3E(7.5)

Table 9-18 presents a summary for Alternative 3E(7.5) including areas, volumes, construction timeframe, and costs.

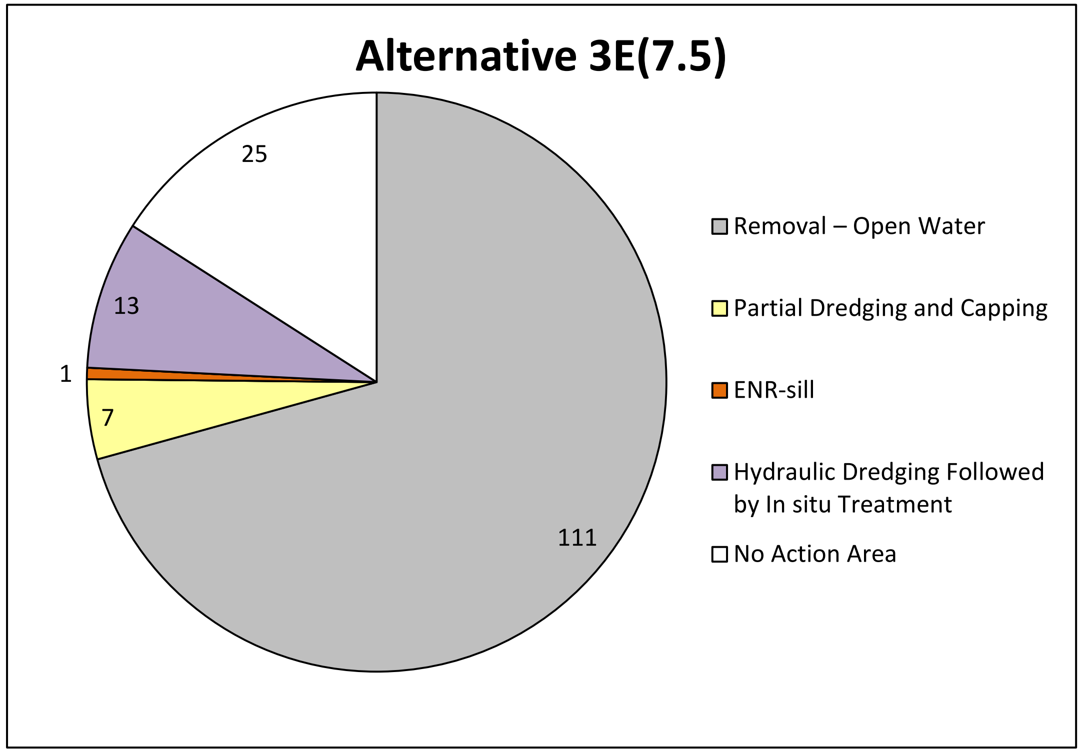
9.13.1 Overall Protection of Human Health and the Environment

Alternative 3E(7.5) emphasizes removal and upland disposal of sediments followed by a combination of remedial technologies—partial dredging and capping, ENR-sill (under low bridges), and diver-assisted hydraulic dredging followed by in situ treatment (underpier areas). This alternative addresses 132 acres of contaminated sediment through these remedial technologies (Table 9-18). Alternative 3E(7.5) has an estimated construction period of 13 years, during which the community, workers, and the environment would be affected as described in Section 9.13.5.

A description of PRG achievements for Alternative 3E(7.5) is listed below (Table 9-8):

Table 9-18
Alternative 3E(7.5) Summary

Areas (acres)	
Removal – Open Water	111
Partial Dredging and Capping	7
Partial Removal and ENR-nav/ENR-nav	0
ENR-sill	1
MNR	0
Hydraulic Dredging Followed by In situ Treatment	13
In Situ Treatment	0
No Action Area	25
Volumes (cy)	
Total Removal Volume	1,080,000
Total Placement Volume	270,000
Construction Timeframe (years)	
Construction Time	13
Costs ($ Million)	
Construction Costs	333
Non-construction Costs	78
Total Costs (rounded)	411



Notes:

1. Numbers in pie chart represent acres; total sediment area is 157 acres. All values are rounded for presentation; apparent discrepancies in totals are due to rounding only.
2. Removal volume is based on the assumptions in Appendix F and includes a design factor of 1.5 multiplied by all neatline dredging volumes excluding underpier areas.
3. Costs are based on assumptions in Appendix E.

cy – cubic yard; ENR-nav – enhanced natural recovery used in the navigation channel; ENR-sill – enhanced natural recovery used in the Sill Reach; MNR – monitored natural recovery

- Alternative 3E(7.5) does not achieve the natural background-based PRG for total PCBs and dioxins/furans for the seafood consumption scenarios (RAO 1), but it achieves significant risk reductions for this RAO (e.g., reducing total excess cancer risks [for total PCBs and dioxins/furans combined] between 78% and 80% in 40 years, depending on the RME scenario).
- For human health direct contact (RAO 2) for arsenic, this alternative is predicted to achieve the netfishing and clamming PRG (7 mg/kg dw) immediately after construction completion, and it may also achieve the PRG in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2). This alternative is predicted to achieve the RAO 3 PRGs (at least 98% of surface sediment locations will be below the PRGs for all key benthic risk driver COCs).
- The total PCB PRGs for RAO 4 (fish) are predicted to be achieved for English sole and brown rockfish.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are required because residual risks are still above the CERCLA risk thresholds, and therefore, institutional controls would be implemented to reduce seafood consumption exposures. Those institutional controls may include RNAs and other forms of notification and controls in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. Further, EW-wide recovery processes would be monitored to assess the reduction in long-term sediment concentrations. Long-term monitoring, maintenance, and institutional controls are required for this alternative, which includes 7 acres of partial dredging and capping, 1 acre of ENR-sill, and 13 acres of in situ treatment.

Considering the factors described in this section, Alternative 3E(7.5) achieves the threshold criterion of overall protection of human health and the environment.

9.13.2 Compliance with ARARs

Alternative 3E(7.5) is expected to comply with MTCA/SMS for protectiveness of human health for direct contact (RAO 2),[140] protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs for these RAOs. The alternative has the same ARAR compliance limitations for protection of human health for seafood consumption (RAO 1) as Alternative 1A(12) (see Section 9.5.2). Modeling predicts that Alternative 3E(7.5) will not attain all natural background-based PRGs. Although the SMS allow for use of a regional background-based cleanup level if it is not technically possible to achieve natural background levels, regional background levels have not yet been established for the geographic area of the EW.

CERCLA compliance with MTCA/SMS ARARs for RAO 1 may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are lower than current model predictions, and PRGs identified in this FS may be attained for certain chemicals in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

In addition, although surface water quality is expected to improve, it will not likely comply with human health surface water quality standards for total PCBs and arsenic.

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[140] As described in Section 9.1.1.2, the modeling using best-estimate model inputs predicts that arsenic concentrations will increase to above the PRG in the long term after construction due to incoming sediment concentrations.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS or surface water ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

With the regulatory framework described in this section, Alternative 3E(7.5) achieves the threshold criterion of compliance with ARARs.

9.13.3 Long-term Effectiveness and Permanence

9.13.3.1 Magnitude and Type of Residual Risk

The remedial measures of Alternative 3E(7.5) would significantly reduce surface sediment contaminant concentrations from existing conditions (Table 9-1a), and the box model predicts that the long-term concentrations will continue to decrease over time (Figures 9-1a through 9-1c).

Endpoints and risk outcomes are described below for Alternative 3E(7.5) (achievement of PRGs for each RAO is discussed in Section 9.13.1):

- **RAO 1 (Tables 9-5a through 9-5d):** long-term residual excess cancer risks to humans consuming resident seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME), 3×10^{-5} (Child Tribal RME), and 7×10^{-5} (Adult API RME) 40 years after construction completion. Predicted residual excess cancer risks of 5×10^{-5} (Adult Tribal RME), 8×10^{-6} (Child Tribal RME), and 2×10^{-5} (Adult API RME) are estimated for humans consuming resident seafood that contain dioxins/furans in the same time period. The RME seafood consumption non-cancer HQs associated with total PCBs (based on the immunological, integumantary, or neurological endpoints) are predicted to be above 1 (4 for Adult Tribal, 9 for Child Tribal, and 4 for Adult API) in the long term (40 years after construction completion). The RME seafood consumption non-cancer HQs associated with total PCBs (based on the developmental endpoint) are predicted to be equal to 1 for the Adult Tribal and Adult API RME scenarios, and above 1 for the Child Tribal RME scenario (HQ of 3) in the long term (40 years after completion of construction). The seafood consumption non-cancer HQs associated with dioxins/furans are predicted to be below 1 for all three RME scenarios (40 years after construction completion).

- **RAO 2 (Table 9-6):** The total direct contact excess cancer risk (for arsenic) is predicted to be less than 1×10^{-5} immediately after construction completion and over the long term. Specifically, at 40 years, excess cancer risks for arsenic are predicted to be 2×10^{-6} and 7×10^{-6} for netfishing and tribal clamming, respectively.[141]
- **RAO 3 (Table 9-3):** No adverse effects to the benthic community are predicted because more than 98% of surface sediment locations are predicted to be below the PRGs for total PCBs and all other key benthic risk driver COCs (immediately after construction completion).
- **RAO 4 (Table 9-7):** Total PCB HQs are predicted to be below 1.0 for English sole and brown rockfish for LOAEL TRV of 2,640 µg/kg ww and below 1.0 for English sole and slightly above 1.0 at 1.1 for brown rockfish for the LOAEL TRV of 520 µg/kg ww 40 years after construction completion.

Physical disturbance (e.g., vessel scour) could expose contaminated subsurface sediment left in place after construction is complete. The greatest exposure potential is from areas outside of the dredge and partial dredge and cap areas, within ENR-sill and in situ treatment areas. Table 9-10 shows that the numbers of core stations remaining with CSL and RAL/SQS exceedances in areas that are partially removed and capped are 5 and 7, respectively, and none would remain in ENR-sill. The corresponding surface areas that leave some degree of contamination in the subsurface are 7 acres in partial dredging and capping, and 1 acre in ENR-sill. These acreages do not necessarily imply that unacceptable subsurface contaminant concentrations exist across the full extent of areas not removed. The majority of the sediments are being remediated through removal actions (124 acres, including 13 acres with diver-assisted hydraulic dredging in underpier areas), which results in a much smaller percentage of the waterway with residual contamination left in place.

9.13.3.2 Adequacy and Reliability of Controls

Alternative 3E(7.5) removes 124 acres (including 13 acres with diver-assisted hydraulic dredging in underpier areas) of contaminated sediment from the open-water and underpier

[141] Arsenic natural background concentrations exceed 1×10^{-6} excess cancer threshold (see Section 9.3.3.2).

areas of the EW and yields a long-term and permanent risk reduction, but will require short-term monitoring and contingency BMPs, where appropriate, to address dredge residuals left behind by diver-assisted hydraulic dredging. Areas that undergo partial dredging and capping (7 acres) would require moderate long-term monitoring and maintenance to confirm that subsurface contamination remains in place. The potential for caps requiring replacement in the future is considered to be low.

Only 1 acre of ENR-sill (under low bridges) and 13 acres of in situ treatment (after diver-assisted hydraulic dredging in underpier areas) under Alternative 3E(7.5) will require a higher level of monitoring and may require contingency actions (Table 9-17). However, this alternative does not leave any contaminated subsurface sediment above the RALs in place in ENR-sill areas (see Section 9.12.3.1 and Table 9-17) that could expose buried contaminated sediment.

Alternative 3E(7.5) requires an Institutional Controls Plan because the alternative is not predicted to achieve PRGs or risk thresholds (even at background concentrations these non-engineered measures would be necessary). The Institutional Controls Plan will include, at a minimum, the same three components as for Alternative 1A(12) (Section 9.5.3.2).

The combination of monitoring, maintenance, and institutional controls, would require 5-year reviews under CERCLA, and contingency actions (if required) are intended to enhance remedy integrity and to allow Alternative 3E(7.5) to be adaptively managed, as needed, based on new information.

9.13.4 Reductions in Toxicity, Mobility, or Volume through Treatment

This alternative actively remediates 13 acres by in situ treatment in underpier areas, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-18).

9.13.5 Short-term Effectiveness

9.13.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices would provide adequate protection to both workers and the community during the 13-year construction period for Alternative 3E(7.5). Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter (due to sediment resuspension and release of dissolved contaminants during dredging), resulting in a period of continued elevated resident seafood consumption risks.

Local transportation impacts (e.g., traffic, noise, or air pollution) from the implementation of this alternative are proportional to the number of train, truck, and barge miles (100,000, 118,200, and 13,800, respectively) estimated to support material hauling operations for the disposal of contaminated sediment and for the transportation of sand, gravel, and armor stone used in capping, ENR-sill, backfilling of dredged areas, RMC, and in situ treatment (see Appendix I).

Work-related accidents may occur during construction and are proportional to the volume of material handled, amount of diver-assisted hydraulic dredging, transportation, and duration of the remediation activities of Alternative 3E(7.5) (Appendix I). This alternative includes 13 acres of diver-assisted hydraulic dredging in underpier locations over twelve construction seasons, which has intrinsic high safety concerns, especially in deeper water and under structures.

9.13.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is expected to occur to some degree during dredging operations, which for Alternative 3E(7.5) would occur over 13 construction seasons. The use of BMPs for reducing the resuspension of contaminated sediments from dredging is discussed in Section 7.5.3. For the purpose of this FS, residuals were assumed to be managed through the placement of an RMC layer over the area dredged for Alternative 3E(7.5) (124 acres, including 13 acres with diver-assisted hydraulic dredging in underpier areas) and over the interior unremediated areas (15 acres), as described for Alternative 1A(12) (Section 9.5.5.2).

For Alternative 3E(7.5), the benthic community within approximately 6.6 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 feet MLLW) would be impacted by active remediation, requiring time to regain ecological functions (approximately 1 or 2 years to recover after first disturbed, and up to 10 years to regain full function; Borja et al. 2010, King County 2010).

This alternative would consume regional resources, primarily in the form of quarry material (sand, gravel, and armor stone), landfill space, and energy. An estimated 270,000 cy of imported granular material is used for capping, ENR, RMC, and backfilling of dredged areas where return to grade is assumed (Table 9-18). The landfill capacity consumed by Alternative 3E(7.5) is proportional to the volume of dredged material removed and disposed of in the landfill (1,300,000 cy, assuming a 20% bulking factor) (see Appendix I). Thermal and electrical energy consumed (from diesel fuel combustion and water treatment due to diver-assisted hydraulic dredging, respectively) during the remediation activities of Alternative 3E(7.5) are estimated to be 1.4×10^8 MJ (see Appendix I).

Estimates of direct and indirect air pollutant emissions associated with Alternative 3E(7.5) are presented in Appendix I. Implementation of this alternative would result in approximately 22,700 metric tons of CO_2 emitted to the atmosphere. The air pollutants generated by this alternative from all combustion activities include particulate matter (as PM_{10} and $PM_{2.5}$, 8.3 and 8.2 metric tons, respectively), CO (120 metric tons), HCs (39 metric tons), VOCs (40 metric tons), NO_x (190 metric tons), and SO_2 (0.39 metric tons). These emissions are primarily the result of removal, transloading, and disposal of dredged contaminated sediment and transportation of materials for in-water placement. Appendix I describes various BMPs for reducing these emissions, such as using alternative fuels.

The carbon footprint of this alternative, defined as the forested area necessary to absorb the CO_2 produced during the remediation activities (based on the sequestration rate for Douglas fir trees), is approximately 5,369 acres-year (Appendix I).

9.13.5.3 Time to Achieve RAOs

Table 9-8 summarizes the predicted times for Alternative 3E(7.5) to achieve RAOs, expressed as the time to achieve the PRGs. This table also reports the time to achieve certain risk reduction milestones for RAO 1 and 2. These times are based on start of construction as year 0 and they take into account the construction period.[142]

For RAO 1, the natural background-based PRGs for total PCB and dioxins/furans are not achieved by Alternative 3E(7.5) within a 40-year period. However, dioxins/furans concentration may achieve the PRG in the long term, depending on the concentration of incoming Green River sediments (Section 9.15.1.2). Alternative 3E(7.5) is predicted to achieve the following risk reduction milestones associated with total PCBs and dioxins/furans:

- A 10^{-4} order of magnitude excess cancer risk for the Adult Tribal RME by year 13 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-6} order of magnitude excess cancer risk for the Child Tribal RME by year 13 (immediately after construction completion) and at year 0 (start of construction), respectively
- A 10^{-4} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for both COCs
- A 10^{-5} order of magnitude excess cancer risk for the Adult API RME at year 0 (start of construction) for dioxins/furans, but this alternative is not predicted to achieve it for total PCBs

Alternative 3E(7.5) is also predicted to achieve 7 mg/kg dw for arsenic in 13 years (immediately after construction completion) for both site-wide and clamming exposure areas, and may achieve 7 mg/kg dw in the long term, depending on concentration of incoming Green River sediments (Section 9.15.1.2).

[142] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years for this alternative, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in this section.

For RAO 3, PRGs are predicted to be achieved, with at least 98% of surface sediment locations below the PRGs immediately after construction completion (by year 13) for total PCBs and for the other key benthic risk driver COCs.
The RAO 4 PRGs for total PCBs for both English sole and brown rockfish are predicted to be achieved immediately after construction completion (by year 13).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and, therefore, have uncertainty in their predictions (see Section 9.15).

9.13.6 Implementability

Alternative 3E(7.5) has a construction period of 13 years, remediates 132 acres, and is administratively implementable. A major implementability challenge for Alternative 3E(7.5) is the extensive use of diver-assisted hydraulic dredging in underpier areas. This alternative assumes the removal, to the extent practicable, of all 13 acres above RALs in underpier areas (Table 9-18). Technical considerations and issues and safety concerns for diver-assisted hydraulic dredging are similar to those described for Alternative 1C+(12), but of greater magnitude considering the increased area of diver-assisted hydraulic dredging (Section 9.7.6).

An additional technical challenge for this alternative is the underpier material placement in areas remediated by in situ treatment (13 acres; Table 9-18). Anticipated access restrictions and placement methods of the activated carbon are similar to those described for Alternative 1B(12) (Section 9.6.6).

A total of 14 acres would be remediated through the use of ENR-sill and in situ treatment in Alternative 3E(7.5); thus, contingency actions could be needed if these technologies do not perform adequately. Therefore, ENR-sill and in situ treatment could require additional administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if any are needed. Additional actions (15% of ENR-sill and in situ treatment areas) are assumed as a contingency for Alternative 3E(7.5) based on the possibility that post-construction monitoring data could indicate inadequate performance in achieving all RAOs in some areas.

The long construction period, large total removal volume, and high potential for low RALs triggering significant additional actions from recontamination are other important implementability considerations for Alternative 3E(7.5).

9.13.7 Cost

The total cost for Alternative 3E(7.5) is $411 million, which includes estimated construction and non-construction costs of $333 and $78 million, respectively, and accounts for costs for contingency, management, and oversight. All costs are NPV and presented in 2016 dollars (see Appendix E for details and cost uncertainties).

9.13.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the SRI/FS. EPA will select the preferred remedy through the Proposed Plan and then will issue the ROD. EPA will evaluate state, tribal, and community acceptance in the ROD, following the public comment period on EPA's Proposed Plan.

9.14 Recontamination Potential

As presented in Section 2.11.3, potential sources of contaminants to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the EW through various pathways. Potential sources can be either historical or ongoing. These pathways include the following:

- Direct discharge into the EW (e.g., CSOs, stormwater, or sheetflow from properties immediately adjacent to the waterway)
- Upstream inputs
- Groundwater discharge
- Bank erosion
- Atmospheric deposition
- Spills and/or leaks to the ground, surface water, or directly into the EW
- Abrasion and leaching of treated-wood structures

As discussed in the SRI (Windward and Anchor QEA 2014), direct discharges and upstream inputs are the predominant sources of sediment inputs to the EW; therefore, those two sources are important to discuss the potential for recontamination. In addition, atmospheric deposition in comparison to direct discharge is also further evaluated. Remaining pathways were determined to be incidental and localized. Most of these pathways are episodic—such as spills and abrasion of treated-wood structures, or highly localized—such as groundwater discharge, bank erosion, and leaching of treated-wood structures, and were not further evaluated for recontamination potential. Potential concerns from sources that can be highly localized will be further investigated during design. Direct discharge and upstream inputs and direct atmospheric deposition onto the waterway itself were further evaluated in this section to assess recontamination potential.

As discussed in Section 9 of the SRI (Windward and Anchor QEA 2014), multiple external sources of contaminant inputs to the EW exist. They reflect both regional and local sources and are the primary factors influencing the surface sediment contaminant concentrations in the long term following any cleanup. This section includes an assessment of the potential for recontamination based on incoming sediment deposition from both upstream and EW lateral sources that deposit in the waterway. This section also summarizes the evaluation of direct atmospheric deposition to the waterway presented in Appendix K. For simplicity, "recontamination" is defined as contaminant concentrations in surface sediments that return to unacceptable levels after a cleanup (e.g., concentrations above any of the RALs), which triggers the need for additional monitoring or some other action, depending on the source. Diffuse, urban sources external to the EW are a key potential pathway of recontamination. Potential localized resuspension and re-deposition of existing contaminated sediment within the EW may also contribute to recontamination. If surface sediment recontamination occurs, it will reflect the aggregate inputs of these internal and external sources, but action may not be needed depending on the level of recontamination observed. Source control actions (see Section 2.12), including those upstream of the site, will affect long-term contaminant concentrations in EW sediments.

9.14.1 Direct Discharge and Upstream Inputs

The recontamination potential within the EW has been evaluated based on incoming sediment deposition from both upstream and EW lateral sources for all nine risk driver COCs. Surface concentrations of deposited sediment were estimated throughout the EW on a

50-foot by 50-foot grid, based on results of the PTM evaluation (see Section 5.4.1 and Appendix B, Part 1) that provide predictions of spatial variation in EW lateral solids deposition at the same resolution.[143] As described in Section 5.4.3, deposition from upstream sources was assumed to be constant throughout the EW for the recontamination evaluation. In situ surface concentrations at year 0 post-construction were assumed to be zero for all COCs for all alternatives in order to focus the evaluation on recontamination potential associated with the contribution of incoming solids deposition, including EW laterals. Therefore, the conclusions of the recontamination evaluation are applicable to all alternatives.

Surface concentrations of deposited sediments in the EW were calculated for all nine key risk driver COCs based on base case (mid-range) assumptions for solids deposition and chemistry (see Section 5.4.5). Current solids and chemistry assumptions for EW lateral inputs were applied for years 1 through 10 post-construction, and future solids and chemistry assumptions (after additional control of sources) were applied to EW lateral inputs for years 11 through 30 post-construction. Surface concentrations are based on initial deposition patterns predicted by the PTM, and do not take into account mixing or spreading of deposited sediments due to vessel operations in the EW (e.g., propwash).

Appendix J (see Figures 7a and 7b) contains maps highlighting areas where surface concentrations of deposited sediments are predicted to exceed RALs for one or more of the nine key risk driver COCs and, for information purposes, where the seven benthic risk driver COCs were predicted to exceed benthic numerical CSL values. These maps represent mid-range value assumptions (base case) for incoming solids inputs and associated chemistry. Maps showing surface concentrations of deposited sediments for the low and high bounding calculations for total PCBs, dioxins/furans, and BEHP are also provided in Appendix J in Figures 8a-b, 9a-b, and 10a-b, respectively.

Figures 9-7a and 9-7b shows areas that may have the potential to recontaminate based on the results of this evaluation. Areas were identified based on surface concentrations predicted to

[143] Deposition patterns predicted by the PTM represent initial deposition from EW lateral sources and do not include redistribution of deposited sediments due to anthropogenic activity (e.g., propwash).

exceed the RAL for any modeled COC at year 10 post-construction (prior to source control being implemented) and at years 10-30 (long-term) for mid-range value assumptions (base case). COCs that may have an increased potential to recontaminate in specific areas include BEHP, 1,4-dichlorobenzene, mercury, and dioxins/furans, generally in localized areas near specific outfalls. Modeled concentrations for 1,4-dichlorobenzene are a result of conservatively using elevated measurements in the modeling dataset, which are more representative of a source that has since been controlled; therefore, exceedances are not likely to persist. Mercury's potential exceedance is predicted to occur in a single grid cell in the EW, where there are only a few samples with relatively high concentrations and variability. Because BEHP and dioxins/furans are ubiquitous components of PVC plastics and combustion processes, respectively, marginal RAL exceedances may occur in the immediate vicinity of outfalls, consistent with other urban areas.

This evaluation does not account for redistribution from propwash or other anthropogenic forces, which would likely decrease the value of predicted concentrations at specific elevated grid cells, but could also result in a slightly larger area with elevated concentrations. In addition, all nearshore outfalls were assigned the same chemistry assumptions in the evaluation (see Appendix B, Part 4). Actual chemistry data from an individual outfall may be different. Therefore, some locations in the EW identified as having elevated recontamination potential may not be representative of actual deposited solids concentrations in those areas.

Areas modeled to have elevated recontamination potential are defined as specific grid cells predicted to have elevated concentrations. The results do not mean recontamination is expected to occur, but that the potential exists based on the modeling assumptions used. It is anticipated that these areas will be considered during the design phase as areas that may require additional source evaluation and control and targeted monitoring following remediation. Uncertainty associated with this evaluation is discussed in Section 9.15 and Appendix J.

9.14.2 Direct Atmospheric Deposition

Contributions from direct atmospheric deposition[144] to the waterway were evaluated in Appendix K. These qualitative assessments indicate that direct atmospheric deposition masses of BEHP and dioxins/furans may be significant relative to mass from the direct discharge pathway. These inputs are distributed across the EW surface area and, while contributing some input of contaminants to the EW, they are not expected to create any localized recontamination concerns. Direct atmospheric deposition masses of arsenic, HPAH, mercury, and total PCBs to the EW water surface are small compared to the direct discharge pathway masses. Note that direct discharge masses also include indirect atmospheric deposition to the contributing drainage basins, which was not estimated separately due to uncertainties in quantifying the indirect pathway.

9.15 Uncertainty Considerations

9.15.1 Surface Sediment Concentration Predictions

9.15.1.1 Bed Replacement Values and Residuals

Sediment bed replacement values are a key input in establishing post-construction (Time 0) concentrations and affect the short-term model-predicted outcomes. For total PCBs, a range of replacement values were developed for remediated areas and interior unremediated areas using low and high residuals thicknesses and concentrations (this range was intended to capture the uncertainty associated with any of the variables that contribute to the actual post-construction surface sediment concentration; Appendix B, Part 3A). However, as shown in Figures 3a, 3b, 4a, 4b, 5a, and 5b in Appendix J, long-term site-wide concentrations are more influenced by other variables, particularly physical factors like extent and depth of sediment mixing, NSRs, and incoming Green River sediment concentrations.

Actual surface sediment concentration immediately following construction in the EW will be largely dependent on dredge residuals concentrations and thickness. Thickness of dredge cut, type of dredge equipment, location-specific sediment characteristics, and use of BMPs

[144] The indirect atmospheric deposition onto the upland drainage basins also contributes to the direct discharge pathway, but the contribution of such atmospheric deposition to the total direct discharges was not estimated as part of this evaluation.

will affect the dredge residuals thickness. The concentration of sediment being dredged (especially the last pass for dredging areas where multiple passes are required) also varies throughout the EW and will influence dredge residuals concentrations. As described in FS Appendix B, Part 5, variables that affect the dredge residuals thickness, concentration, and distribution include hydrodynamic and operational conditions within the EW during dredging and placement of RMC, including water depth, anticipated duration it would take to place clean material over the entire open-water remediation area, and frequency of ongoing vessel traffic in the EW that causes sediment resuspension and sediment bed mixing.

Other factors that could affect replacement value are evaluated in FS Appendix B, Part 5, including sand cover thickness (RMC), which has minimal effect on replacement values, and organic carbon content of sand cover, which is expected to rebound to baseline levels of organic carbon within a few years following RMC placement due to incoming sediment organic carbon concentrations and the load of organic material that accumulates from biological activity at the site (Appendix B, Part 5).

9.15.1.2 SWAC Values (Box Model) and Point Surface Concentrations (Point Mixing Model)

Uncertainty in predictions of SWAC values (box model evaluation) and point surface concentrations (point mixing model evaluation) are a result of uncertainty in input parameters (i.e., NSRs, chemistry assumptions) and uncertainty induced by the methodology used to complete the calculations. This section provides a brief overview of uncertainty in the calculations, which is discussed in detail in in Appendix J.

Uncertainties due to input data and methodology were assessed through sensitivity and bounding evaluations, which are discussed in detail in Section 2.3 of Appendix J. The results of these evaluations included an understanding of the impacts on SWAC and point surface concentrations due to variation in the values of input information. A summary of these impacts is provided below:

- Variability in Green River chemistry and range in its inputs has the largest impact on the SWAC values based on its potential range of values (approximately by up to 25% through year 10 post-construction and up to 45% by year 30 post-construction; see

Figures 3b and 4b in Appendix J). In the very long term (i.e., 30 years post-construction and beyond), Green River chemistry is the primary controlling parameter, because it is the primary determinant of the concentration the site will equilibrate to (i.e., the EW sediment concentrations reflect incoming Green River sediments). In the long term, higher Green River concentrations will result in higher site-wide SWACs. Green River chemistry has greater effect on alternatives with more active remediation and less reliance on natural recovery because site-wide SWACs are lower following construction for a more active alternative (largely due to the change in remediation technology in underpier areas), and therefore it equilibrates more rapidly to the concentration of incoming Green River sediments. The variation of all other variables considered falls within the envelope of potential SWAC values calculated by varying the Green River chemistry values.

- Other observations on SWACs outside of the impacts of Green River chemistry:
  - Variability in EW laterals chemistry has very little impact on predicted SWAC values (less than 5% at years 10 and 30 post-construction). Although input parameters from the LDW were not analyzed in the sensitivity analysis, lateral and resuspended LDW bedded sediment inputs are also expected to have very little impact on predicted SWAC values based on the total mass of loads to the EW from these two sources (0.7%; see Section 5.1) compared to other upstream sources (i.e., Green River; 99%).
  - A smaller NSR for the EW results in higher predicted SWAC values. The range in inputs for NSR can change predicted SWAC values by up to 15% through year 10 post-construction and up to 35% by year 30 post-construction. A higher NSR reduces the site-wide SWAC by reducing the time needed for the site to equilibrate to net incoming concentrations (i.e., increases the rate of natural recovery). Use of a variable NSR within the EW did not have any appreciable effect on the SWAC predictions, compared to best estimate calculations for any years. In general, NSR has a greater effect on alternatives with more reliance on natural recovery.
  - A larger value of maximum mixing depth results in lower predicted SWAC values (by approximately 5% at years 10 and 30 post-construction).
  - Decreasing the surface area of the EW that fully mixes within a set timeframe decreases the predicted SWAC values (by less than 5% at years 10 and 30 post-

construction, while increasing the timeframe for full mixing to occur increases the predicted SWAC values (by approximately 10% at year 10 post-construction and less than 5% at year 30 post-construction).

- Variability in bioavailability has little impact on predicted SWAC values. Percent reduction in bioavailability due to in situ treatment was one of the most sensitive parameter 0 to 10 years following construction, but was less sensitive in the long term. If in situ treatment is more effective at reducing bioavailability, then site-wide SWACs are predicted to be effectively lower. The range in inputs for the percent reduction in bioavailability due to in situ treatment can change predicted SWAC values by 30% at year 10, but its influence is reduced to up to 20% by year 30. This parameter only affects alternatives that employ in situ treatment.
- Modifying dredge residuals concentration results in a slightly greater change in predicted SWAC values than modifying dredge residuals thickness. Influence on year 30 post-construction SWAC values is slightly more for each factor, but each results in less than 10% change by year 30 post-construction.
- A smaller percentage exchanged between open water areas and underpier areas results in an increase in predicted SWAC values. Underpier exchange is another sensitive parameter 0 to 10 years following construction, but is not a very sensitive parameter in the long term. The model results predict that more underpier exchange would result in a higher temporary increase in site-wide SWAC following construction, due to the distribution of higher concentration underpier sediments into the larger, mostly remediated open-water areas. Less underpier exchange reduces the site-wide SWAC because the higher concentration sediments in the underpier remain localized. The range in inputs for underpier exchange can change predicted SWAC values by up to 20% at year 10 post-construction, but its influence is less than 10% by year 30. Underpier exchange has more effect on alternatives with MNR in the underpier area.

Sensitivity analysis was conducted for Alternatives 1A(12) and 2B(12), and a total of 18 different scenarios for Alternative 1A(12) and 20 different scenarios for Alternative 2B(12) were evaluated for total PCBs (see Appendix J).[145] The results of the sensitivity analysis were used to develop scenarios (combinations of input parameter values) that result in the lowest and highest SWAC predictions for Alternatives 1A(12) and 2B(12). This bounding analysis was done to quantify the maximum uncertainty in predicted SWAC values from the box model evaluation for all remedial alternatives. The lowest and highest bounding scenarios are determined using results of the sensitivity analysis for Alternatives 1A(12) and 2B(12) that showed which parameters caused the SWAC to increase or decrease (see Figures 3b and 4b in Appendix J).

The overall range of predicted SWACs for the highest and lowest bounding and base case scenarios suggests that SWAC values for the EW predicted by the box model could vary by up to +125% and -75% at year 10 and by up to +110% and -80% at year 30 for Alternatives 1A(12) and 2B(12), respectively (see Figures 5a and 5b in Appendix J). This is due primarily to the significant influence of the Green River chemistry and NSR in the EW. Based on four additional high and low bounding scenarios conducted on selected factors (which hold the Green River chemistry and NSR at base case values, while varying all other parameters), the SWAC values predicted by the box model vary by up to +50% and -40% at year 10 and by up to +20% and -25% at year 30 for Alternatives 1A(12) and 2B(12), respectively.

Figures 9-8a (Alternative 1A(12)) and 9-8b (Alternative 2B(12)) present graphically the results of the sensitivities in total PCB SWACs (calculated with the box model evaluation) for the eight model parameters, compared to base case, at years 10 and 30 post-construction. Based on Appendix J, while the sensitivity of the predicted SWAC calculations to individual parameters differed somewhat between the two alternatives, the range in predicted SWAC values based on the full range of uncertainty in the input parameters was similar for both alternatives. Therefore, interpretation and comparison of SWAC predictions to PRGs for each alternative presented in Section 9 should be considered carefully with respect to the uncertainty of the model.

[145] Alternative 1A(12) only has 18 scenarios because it does not have underpier in situ treatment, and therefore does not have sensitivity parameters for bioavailability.

The uncertainty of SWAC comparisons is further reinforced when considering analytical precision and field variability. Based on typical analytical relative percent differences and field variability, any individual or mean value within 20% of the cleanup standard is considered indistinguishable from the cleanup standard and, therefore, the measured value is in compliance.

Section 5.3.2 describes the range of incoming solids concentrations for all human health risk drivers. For arsenic, the low and high bounding range of incoming sediment concentrations is 7 mg/kg dw and 10 mg/kg dw, respectively. All alternatives achieve the long-term model predicted concentration, which for the base case is 9 mg/kg dw. If the incoming sediment concentration is closer to 7 mg/kg dw, the alternatives would meet the natural background PRG of 7 mg/kg dw, when using the UCL95 for calculating natural background.

For dioxins/furans, the low and high bounding range of incoming sediment concentrations is 2 ng TEQ/kg dw to 8 ng TEQ/kg dw. All active alternatives achieve the long-term model predicted concentration, which for the base case is 6 ng TEQ/kg dw.

9.15.1.3 Recontamination Evaluation (Grid Model)

This section provides a brief overview of uncertainty in the evaluation of recontamination potential, which is discussed in detail in Section 5.4 of Appendix J.

The primary sources of uncertainty for this evaluation are associated with input data for upstream solids and chemistry (discussed in Section 5.1.2) and EW lateral solids and chemistry (discussed in Section 5.1.3). Since the recontamination evaluation focused on impacts from EW laterals, uncertainty in solids inputs and chemistry assumptions for EW laterals was taken into account through a bounding evaluation as described in Section 4.5 of Appendix J.

A review of the bounding evaluation on the areas identified as having elevated recontamination potential show the following trends:

- All COCs evaluated in the bounding evaluation had fewer areas of concern for the low bounding simulation compared to the base case or high bounding simulation. Total PCBs had no areas of concern for the low bounding simulation.
- All COCs evaluated in the bounding evaluation had additional areas of concern based on the high bounding simulation. However, these areas represent a small portion of the EW area and do not extend far from source outfalls identified in the base run.
- Dioxins/furans had a small reduction in areas of concern once proposed future source control actions were accounted for. Proposed source control actions did not reduce total PCBs and BEHP locations or reduce their areas.

Considerations associated with the methodology used to evaluate recontamination potential that could introduce uncertainty in the evaluation include assumptions for surface concentrations at year 0 post-remediation and vertical mixing assumptions. Incorporation of predicted post-remediation conditions were not included in the predictions in order to focus the evaluation solely on impacts of incoming sediment deposition on recontamination potential to help inform source control. Actual concentrations over time would be impacted by what concentrations are actually present at Time 0. The deposition patterns predicted by the PTM for EW laterals do not take into account impacts of resuspension due to vessel operations. Therefore, deposition patterns predicted by the PTM (used as input for the grid model evaluation) for individual elevated grid cells would likely be more spread out, resulting in lower contaminant concentrations in those grid cells due to a wider distribution of deposited material over a larger area. This could result in a larger or smaller area with the potential for recontamination, depending on the concentration of the deposited material and the amount of propwash.

9.15.2 Other Uncertainties

The performance of the remedial technologies with respect to long-term effectiveness, short-term effectiveness, implementability, and cost represent an uncertainty in this analysis. In particular, the performance and technical challenges associated with the technologies for remediating underpier areas are a key uncertainty in this FS. The performance of MNR in underpier areas is less certain compared to the other remedial technologies (ENR-sill, in situ treatment, or removal); however, MNR poses very few technical challenges. While the performance of in situ treatment is considered more certain than for MNR, it still depends on a range of physical and chemical factors. In situ treatment also includes important technical challenges for placing material on steep slopes in difficult-to-access areas. Finally, diver-assisted hydraulic dredging is associated with large uncertainty in terms of both performance and technical implementability. Performance of diver-assisted hydraulic dredging is uncertain with respect to the quantity of contaminated sediment remaining due to conditions under piers (e.g., riprap interstices and debris). Technical implementability is also uncertain with respect to the construction timeframe, diver health and safety, and costs associated with removing underpier sediments in deep water.

The performance of the remedial technologies outside of underpier areas also have uncertainties, which are mitigated by adaptive management. Dredging results in the release of contaminants to the water column (which can elevate fish and shellfish tissue contaminant concentrations over the short term) and dredge residuals to the sediment surface. As described in Appendix A, full removal of all contaminated sediment is not possible in many areas near structures, where setbacks and stable slopes required for structure protection will leave some contaminated sediments behind. Long-term site-wide predictions will depend on the location and amount of sediment remaining adjacent to structures, and the potential for it to be disturbed from propwash. Measures will be incorporated into the design to address this remaining sediment, along with monitoring and adaptive management following construction.

Capping, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment require ongoing monitoring and may need periodic maintenance. MNR performance may be slower or faster than predicted and may require additional monitoring or contingency actions. These uncertainties would be managed in the long term under the action alternatives by the required monitoring, contingency actions, and repairs as needed. Cost estimates in this FS include the costs of these long-term management activities. These activities would be enforceable requirements under a Consent Decree (or similar mechanism), and EPA is required to review the effectiveness of their selected remedy no less frequently than every 5 years.

In addition, uncertainty exists in the predictions of resident seafood tissue contaminant concentrations and associated human health risks (from the total PCB average surface sediment concentration estimates). This uncertainty is driven by: 1) exposure assumptions from the HHRA; and 2) assumptions used in the food web model such as uptake factors and future water concentrations. The predictions of resident seafood tissue contaminant concentrations and risks are nevertheless useful for comparing the alternatives to one another because the uncertainties are the same for all alternatives, and therefore all of the alternatives should be affected similarly.

As discussed in Sections 2.9.2 and 8.3.4, the configuration and depth of the navigation channel could be modified in the future. These potential modifications would affect the post-construction conditions of the alternatives by removing additional material (e.g., RMC that had been placed as part of remediation) or requiring additional slope stability in areas where contaminated sediment is left behind (e.g., the toe of a cap bordering the navigation channel). This uncertainty is mitigated through the design and permitting process, which will require that any potential navigation modifications would not reduce the environmental protectiveness of the remedy in the EW, and that EPA is consulted during the permitting process.

9.16 Managing COCs Other than Risk Drivers

In addition to the risk drivers assessed, additional COCs were identified in both the human health and ecological risk assessments (Table 3-14) (Windward 2012a, 2012b). As summarized in Section 3, COCs were defined as detected contaminants with HQs greater than 1 (for both risk assessments) or excess cancer risk estimates greater than 1×10^{-6} (for human health). The risks associated with these other COCs were very small compared to the risks associated with the risk drivers. In addition, other COCs that are not risk drivers are always co-located with risk drivers and are therefore addressed in the remedial footprints (see Section 6.2.1). This section evaluates how concentrations of these other COCs would change following implementation of the various alternatives and how these changes would achieve risk reduction.

9.16.1 Human Health

Three risk drivers were identified based on the seafood consumption scenarios in the HHRA (total PCBs, cPAHs, and dioxins/furans), and one risk driver was identified based on the direct sediment contact scenarios (arsenic). Additionally, the following summarizes the COCs not identified as risk drivers for the HHRA:[146]

- **Seafood consumption** – arsenic, cadmium, PCP, alpha-BHC, dieldrin, total chlordane, heptachlor epoxide, and mirex
- **Direct sediment contact** – cPAHs, total PCBs, and total TEQ[147]

These COCs were not designated as risk drivers because of their limited contribution to overall risk and because of uncertainties associated with the risk estimates for these contaminants (see Section 3). Table 9-19 summarizes the risks associated with these COCs and the expected management of these risks through sediment remediation. In general, these contaminants are not expected to pose significant residual human health risks after remediation of EW sediments primarily because of the following reasons:

1. Baseline concentrations are similar to background (arsenic).
2. Low magnitude of threshold exceedance (cadmium); cadmium concentrations above SQS will be addressed by remedial action.
3. Low detection frequencies in tissue (pentachlorophenol detected in two clam tissue samples, alpha-BHC detected in two rockfish samples and one geoduck sample, and heptachlor epoxide detected in one rockfish and one crab sample).
4. They were never detected in sediment (alpha-BHC, heptachlor epoxide, mirex, and dieldrin) or rarely detected in sediment (total chlordane detected in one sample and PCP detected in eight sediment samples).
5. Risks for direct sediment contact scenarios are within EPA's target risk range, and site-wide sediment concentrations are predicted to decrease by a factor of 2 to 9 following remediation (total PCBs and total TEQ). Clamming area sediment concentrations are also expected to decrease based on remediation of these areas (e.g., by a factor of 10 to 14 for the alternatives for cPAHs).

Details regarding this rationale are presented in Table 9-19, and these non-risk driver COCs are discussed further in Section A.7 of the baseline HHRA (Windward 2012b).

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[146] No COCs or risk drivers were identified based on exposure to surface water.

[147] Total TEQ is equal to the sum of PCB TEQ and dioxin/furan TEQ.

Table 9-19
Remaining Human Health COCs for Consideration in FS and Expected Risk Outcomes

Human Health COC	Risk Estimate	Additional Considerations	Conclusion
Seafood Consumption Scenarios			
Arsenic	2×10^{-4} [a]	EW sediment concentrations were similar to or lower than those in samples collected from background areas in Puget Sound (see Section B.5.5.1.2 of the HHRA [Windward 2012b]).	Baseline concentrations are within background range.
Cadmium	HQ = 2[b]	There is considerable uncertainty associated with the consumption rates for the child tribal scenario and the HQ is more than an order of magnitude lower than that for total PCBs (HQ of 58); Cadmium HQs for the other two RME scenarios are less than 1; EW sediment SWAC (0.66 mg/kg dw) less than the 90th percentile PSAMP rural Puget Sound concentration (0.73 mg/kg dw)	Baseline concentrations are within background range; low magnitude of threshold exceedance; tissue concentrations may decrease following remediation
Pentachlorophenol	2×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk, low detection frequency in EW tissue samples (detected in two clam tissue samples), and low detection frequency in sediment (4.6%).	Baseline risk is already within EPA's Target Risk Range
alpha-BHC	4×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and low detection frequency in EW tissue samples (17%) and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.
Dieldrin	8×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and detected in less than half of EW tissue samples (two rockfish and one geoduck sample) and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.
Total chlordane	2×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.
Heptachlor epoxide	2×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and low detection frequency in EW tissue samples (one rockfish sample and one crab sample) and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.
Mirex	4×10^{-6} [a]	Contributes less than 1% of the total excess cancer risk and detected in less than half of EW tissue samples (detection frequency is 43%) and never detected in sediment.	Baseline risk is already within EPA's Target Risk Range.

Table 9-19

Remaining Human Health COCs for Consideration in FS and Expected Risk Outcomes

Human Health COC	Risk Estimate	Additional Considerations	Conclusion
Direct Sediment Contact Scenarios			
Total PCBs	3×10^{-6} [c]	Contributes less than 10% of the total excess cancer risk. Based on Table 9-1, concentrations in sediment are predicted to decrease by a factor of 3 to 9 for PCBs (depending on the alternative), indicating that post-remedy risks should be below 1×10^{-6}. [d]	Baseline risk is already within EPA's Target Risk Range; post-remedy risk expected to be less than 1×10^{-6} for all alternatives based on predicted sediment concentrations.
Total TEQ	2×10^{-6} [c]	Contributes less than 10% of the total excess cancer risk. Based on Table 9-1, concentrations in sediment are predicted to decrease by a factor of 3 to 9 for PCBs and 2 to 3 for dioxins/furans (depending on the alternative), indicating that post-remedy risks should be below 1×10^{-6}. [d]	Baseline risk is already within EPA's Target Risk Range; post-remedy risk expected to be less than 1×10^{-6} for all alternatives based on predicted sediment concentrations.

Notes:

a. Risks shown are for the adult tribal RME seafood consumption scenario.
b. Non-cancer HQ is for the child tribal RME seafood consumption scenario.
c. Risks shown are for the tribal clamming RME scenario.
d. Risk reductions are based on predicted site-wide concentrations because predictions for the tribal clamming exposure areas (on which the risks in the HHRA were based) were not available.

BHC – benzene hexachloride
COC – contaminant of concern
EPA – Environmental Protection Agency
EW – East Waterway
HHRA – human health risk assessment
HQ – hazard quotient
PCB – polychlorinated biphenyl
PSAMP - Puget Sound Ambient Monitoring Program
RME – reasonable maximum exposure
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent
TRV – toxicity reference value

9.16.2 Ecological Health

The risk drivers identified based on the ERA included the 29 COCs above the SQS (for benthic invertebrates), TBT (for benthic invertebrates), and total PCBs (for fish). Additionally, the following summarizes the COCs not identified as risk drivers for the ecological receptors:[148]

- **Benthic invertebrates** – total DDTs (based on DMMP) and naphthalene (based on one porewater result)
- **Crabs** – cadmium, copper, and zinc
- **Fish** – cadmium, copper, vanadium, and TBT

These COCs were not designated as risk drivers because of the high levels of uncertainties and/or the low LOAEL HQs. Table 9-20 summarizes the risks associated with these COCs and the expected management of these risks through sediment remediation. In general, these contaminants are not expected to pose significant residual ecological risks after remediation of EW sediments primarily because of the following reasons:

1. Total DDTs were detected in only eight sediment samples, which all contained total PCB concentrations above the RAL and are within the remedial footprint.
2. Naphthalene was identified as a COC based on one porewater result. The sediment in the vicinity of the porewater is within the remediation footprint. Sediment concentrations of naphthalene in this area are expected to be reduced following remediation.
3. Cadmium, copper, zinc, and TBT sediment PRGs have been developed for benthic invertebrates. Therefore, remediation will result in reduced concentrations of these contaminants.
4. Baseline concentrations are less than or similar to background (cadmium, copper, and vanadium).

Details regarding this rationale are presented in Table 9-20, and these non-risk driver COCs are discussed further in Section A.7 of the baseline ERA (Windward 2012a)

[148] No COCs or risk drivers were identified for wildlife (bird and mammal) ecological receptors.

Table 9-20
Remaining Ecological COCs for Consideration in FS and Expected Risk Outcomes

Ecological COC	Exposure Pathway	Maximum NOAEL-Based HQ	Maximum LOAEL-Based HQ	Additional Considerations[a]	Conclusion
Benthic Invertebrates					
Total DDTs	sediment	na	1.4	Uncertainty in exposure data (i.e., detection frequency of 5.6% in sediment); both of the sediment samples above the effects threshold contain PCBs above the RAL, and therefore the samples will be addressed by remediation.	Low magnitude of threshold exceedance; sediment concentrations may decrease following remediation
Naphthalene	pore-water	300	9	High uncertainty in effects data; only one porewater sample exceeded the LOEC and naphthalene did not exceed the SMS in any sediment samples. Area of porewater exceedance is within the remediation footprint.	Exceedance limited to a single sample; high level of uncertainty
Crabs					
Cadmium	tissue residue	6.0	1.4	Uncertainty associated with effects data; maximum exceedance of LOAEL is less than 2; EW sediment SWAC (0.66 mg/kg dw) less than the 90th percentile PSAMP rural Puget Sound concentration (0.73 mg/kg dw). Sediment concentrations above the SMS will be remediated, resulting in reduction in cadmium concentrations.	Baseline concentrations are within background range
Copper	tissue residue	11	1.1	Uncertainty associated with effects data; maximum exceedance of LOAEL is less than 2; EW sediment SWAC (62 mg/kg dw) similar to the 90th percentile PSAMP rural Puget Sound concentration (50 mg/kg dw). Sediment concentrations above the SMS will be remediated, resulting in reduction in copper concentrations.	Baseline concentrations are within background range
Zinc	tissue residue	4.2	1.5	Uncertainty associated with effects data; maximum exceedance of LOAEL is less than 2. Sediment concentrations above the SMS will be remediated, resulting in reduction in zinc concentrations.	low magnitude of threshold exceedance; tissue concentrations may decrease following remediation
Fish					
Cadmium	dietary	13	2.5	High uncertainty in effects data; EW sediment SWAC (0.66 mg/kg dw) less than the 90th percentile PSAMP rural Puget Sound concentration (0.73 mg/kg dw).	Baseline concentrations are within background range

Table 9-20

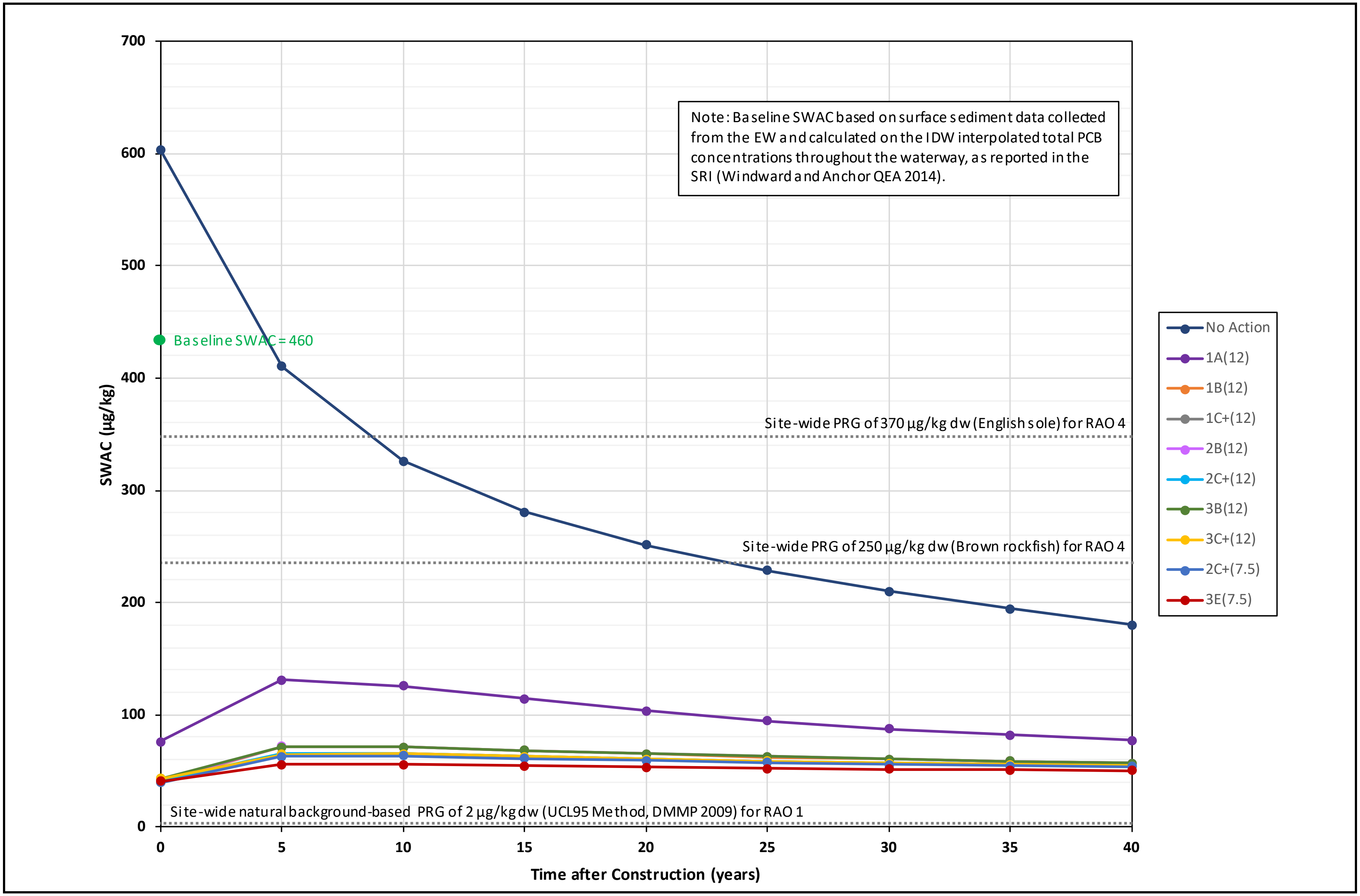
Remaining Ecological COCs for Consideration in FS and Expected Risk Outcomes

Ecological COC	Exposure Pathway	Maximum NOAEL-Based HQ	Maximum LOAEL-Based HQ	Additional Considerations[a]	Conclusion
Copper	dietary	2.2	1.1	Medium uncertainty in effects data; exceedance of LOAEL is low; EW sediment SWAC (62 mg/kg dw) similar to the 90th percentile PSAMP rural Puget Sound concentration (50 mg/kg dw).	Baseline concentrations are within background range
Vanadium	dietary	9.5	1.9	High uncertainty in effects data; EW sediment SWAC (65.7 mg/kg dw) was less than the 90th percentile PSAMP rural Puget Sound concentration (64 mg/kg dw).	Baseline concentrations are within background range
TBT	tissue residue	14	1.4	High uncertainty in effects data; 3 of 13 individual rockfish concentrations exceeded the LOAEL (overall sitewide EPC did not exceed LOAEL). Sediment PRG developed for benthic invertebrates has been used to identify the remedial footprint. TBT sediment concentrations following remediation will be reduced.	Low magnitude of threshold exceedance; tissue concentrations may decrease following remediation

Notes:

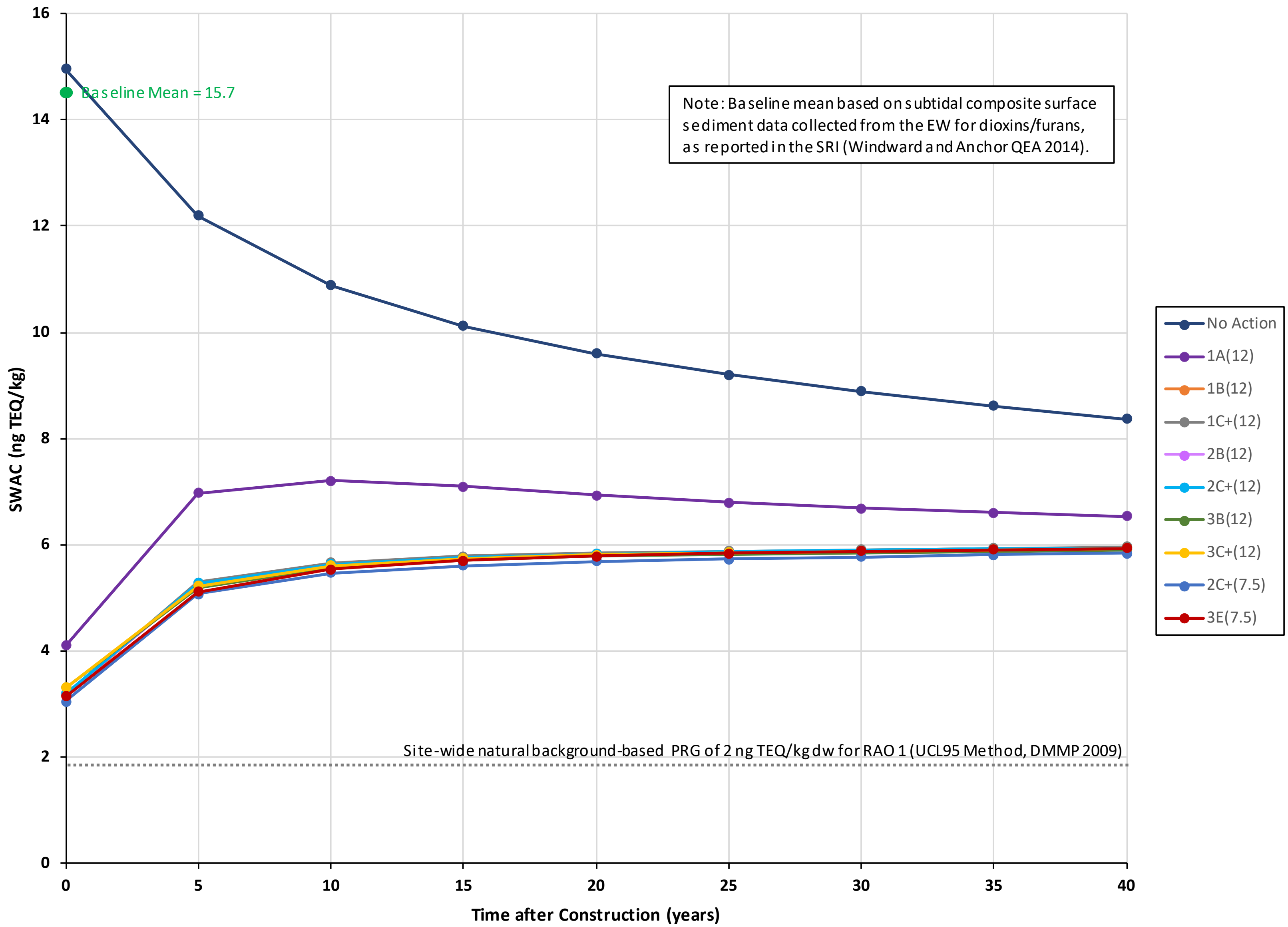
a. More details are provided in Table A.7-1 (for benthic invertebrates and crabs) and in Table A.7-2 (for fish) of the ERA (Windward 2012a).

COC – contaminant of concern
DDT – dichlorodiphenyltrichloroethane
ERA – ecological risk assessment
EW – East Waterway
FS – feasibility study
HQ – hazard quotient
LOAEL – lowest-observed-adverse-effect level
LOEC – lowest-observed-effect concentration
NOAEL – no-observed-adverse-effect level
PCB –polychlorinated biphenyl
PRG – preliminary remediation goal
PSAMP – Puget Sound Ambient Monitoring Program
RAL – remedial action level
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SWAC – spatially-weighted average concentration
TBT – tributyltin
TRV – toxicity reference value



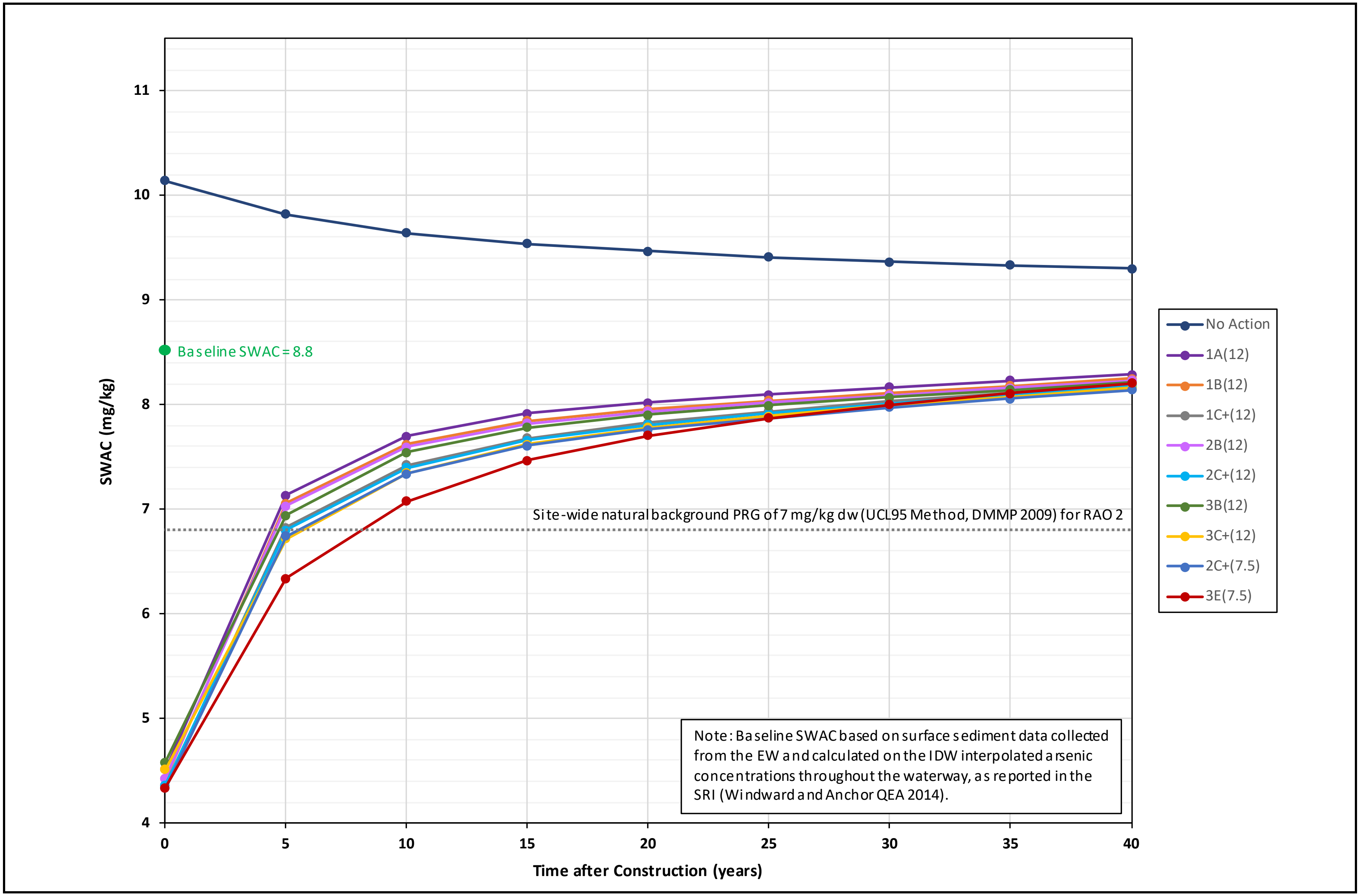
µg/kg = microgram per kilogram
dw = dry weight
IDW = inverse distance weighting
PCB = polychlorinated biphenyl
RAO = remedial action objective
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
PRG = preliminary remediation goal
UCL95 = 95% upper confidence limit on the mean

Figure 9-1a
Predicted Site-wide SWAC for Total PCBs Over Time
Feasibility Study
East Waterway Study Area



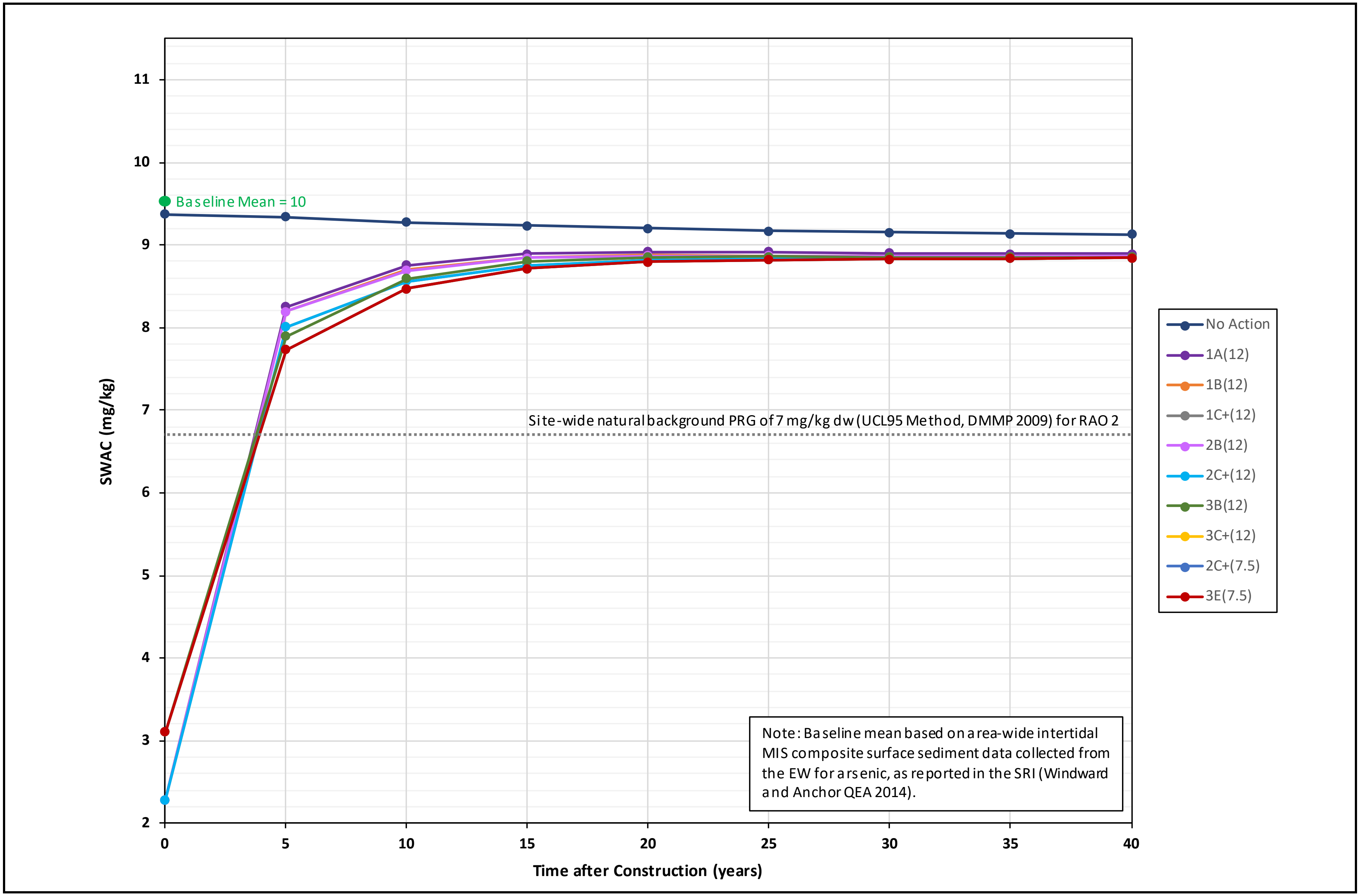
dw = dry weight
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
PRG = preliminary remediation goal
RAO = remedial action objective
kg = kilogram
ng = nanogram
TEQ = toxic equivalent
UCL95 = 95% upper confidence limit on the mean

Figure 9-1b
Predicted Site-wide SWAC for Dioxins/Furans Over Time
Feasibility Study
East Waterway Study Area



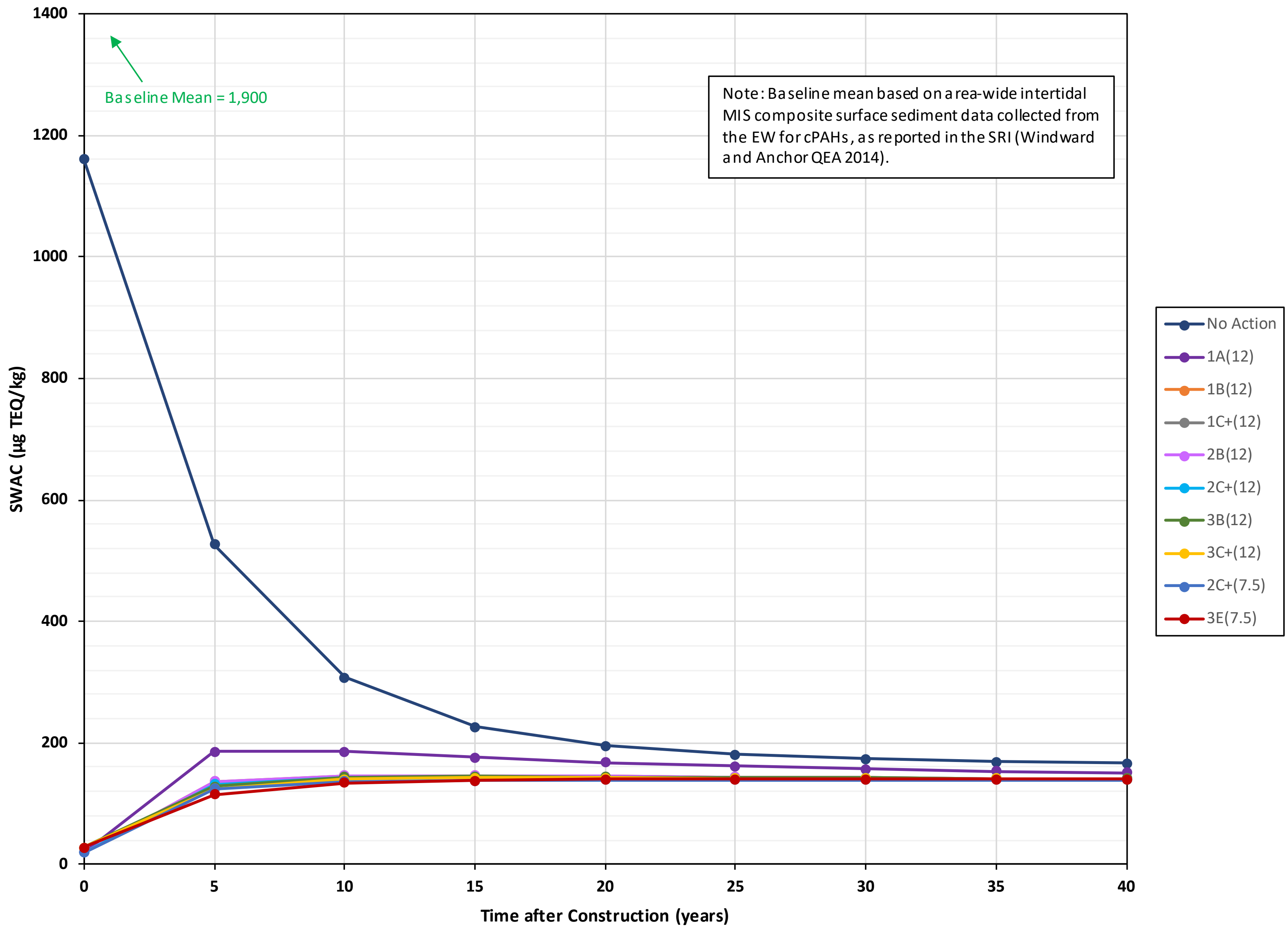
dw = dry weight
mg/kg = milligram per kilogram
PRG = preliminary remediation goal
RAO = remedial action objective
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
UCL95 = 95% upper confidence limit on the mean

Figure 9-1c
Predicted Site-wide SWAC for Arsenic Over Time
Feasibility Study
East Waterway Study Area



dw = dry weight
mg/kg = milligram per kilogram
PRG = preliminary remediation goal
RAO = remedial action objective
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
UCL95 = 95% upper confidence limit on the mean

Figure 9-2a
Predicted Clamming Area SWAC for Arsenic Over Time
Feasibility Study
East Waterway Study Area

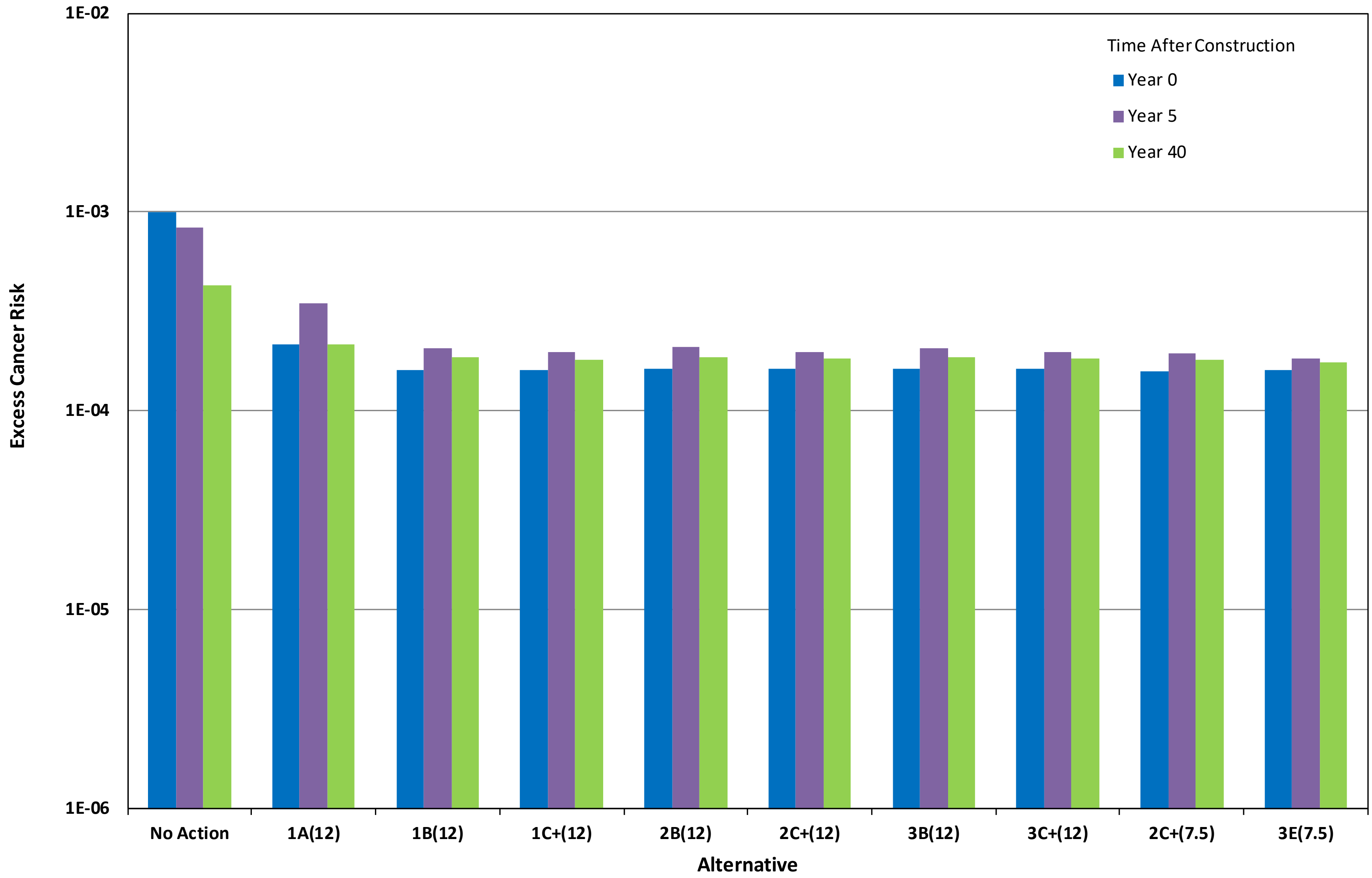


Notes:

SWACs are shown for informational purposes. cPAHs are a risk-driver COC for RAO 1 for consumption of clams; however, a PRG was not developed because the clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop a sediment RBTC based on clam consumption (see Section 3.3.4).

µg = microgram
cPAH = carcinogenic polycyclic aromatic hydrocarbon
dw = dry weight
kg = kilogram
SRI = Supplemental Remedial Investigation
SWAC = spatially-weighted average concentration
TEQ = toxic equivalent

Figure 9-2b
Predicted Clamming Area SWAC for cPAHs Over Time
Feasibility Study
East Waterway Study Area



PCB = polychlorinated biphenyl; RME = reasonable maximum exposure

Figure 9-3a
Estimated Total PCB Excess Cancer Risks for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area

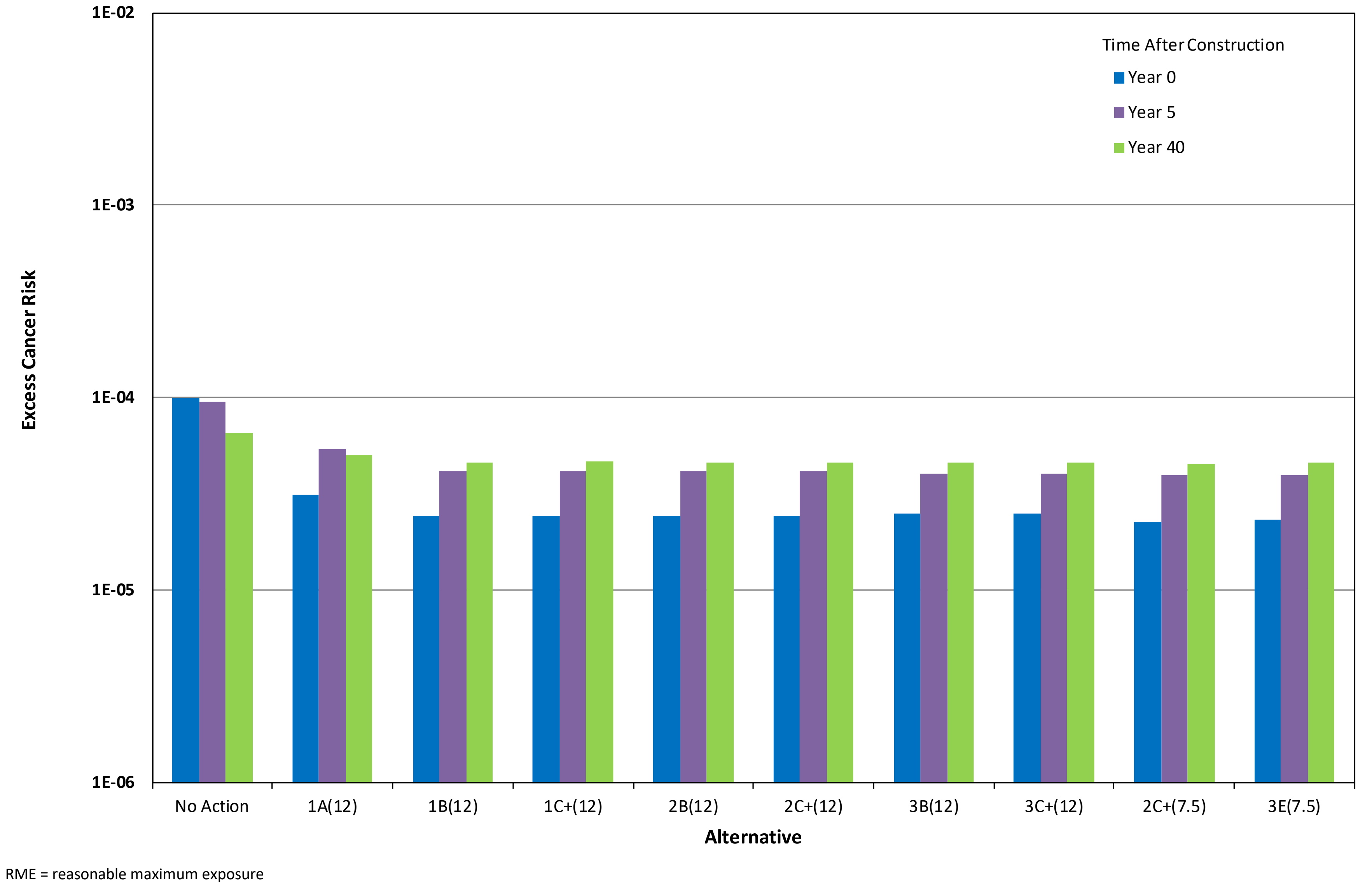
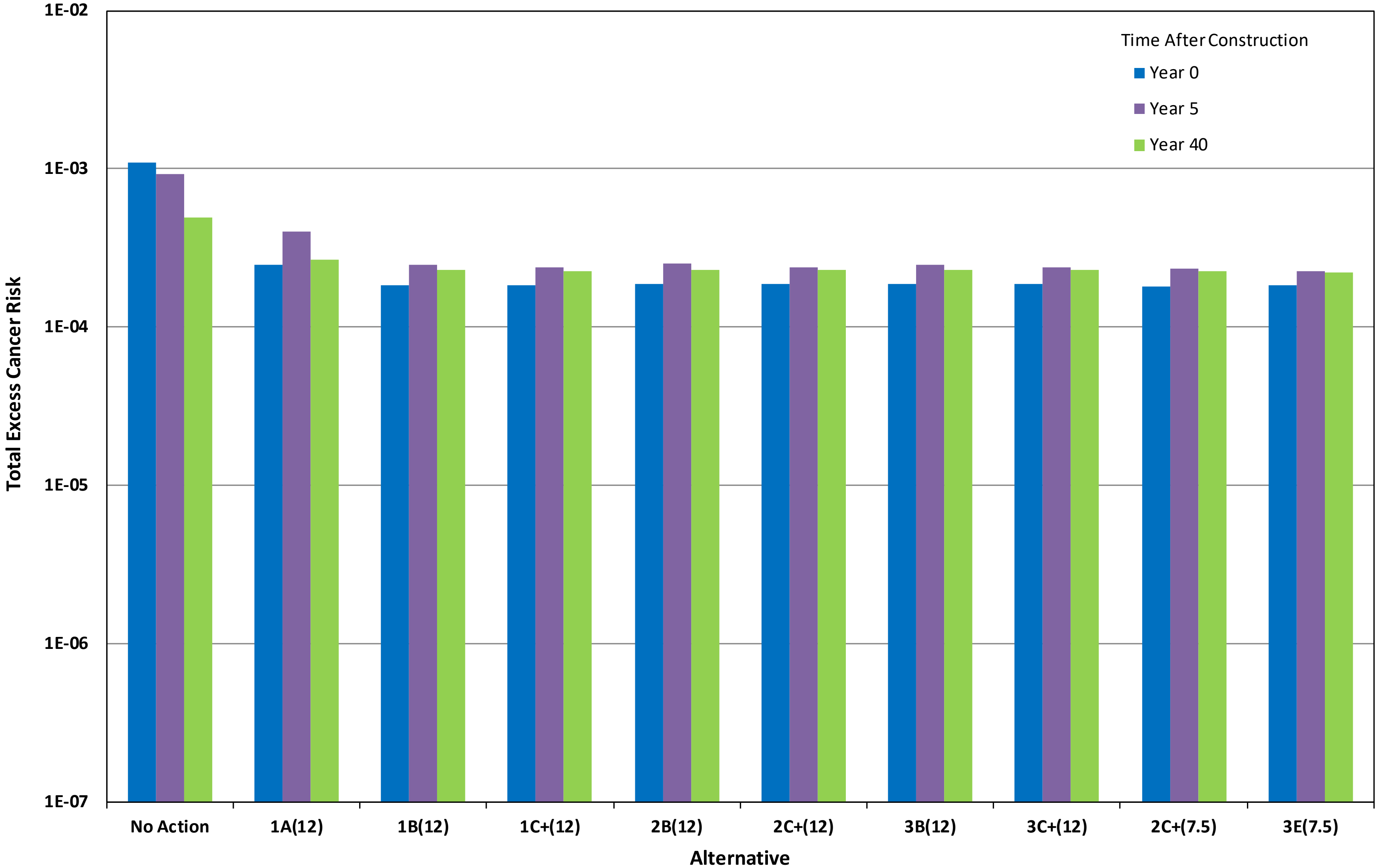
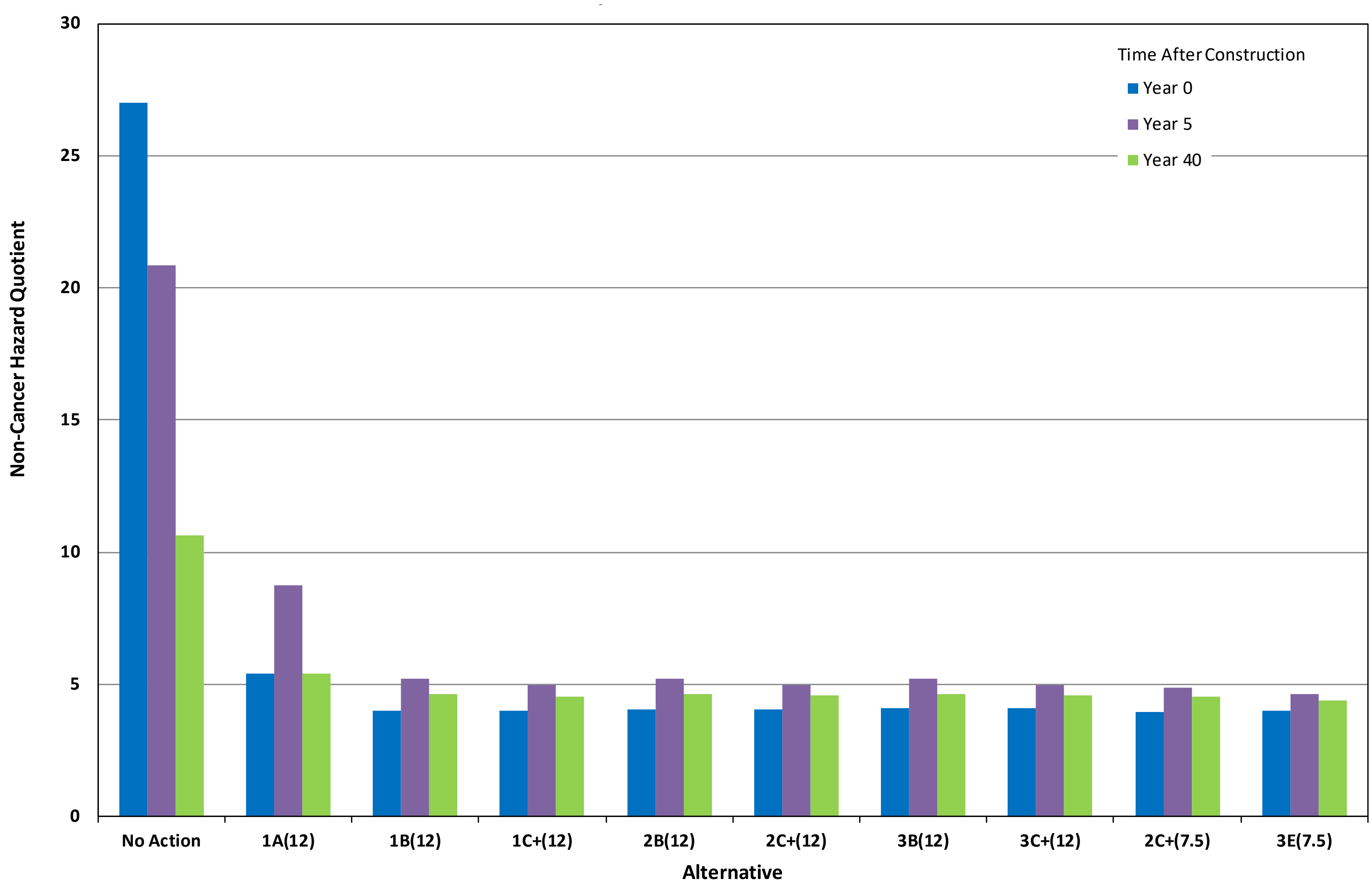


Figure 9-3b
Estimated Dioxin/Furans Excess Cancer Risks for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area



RME = reasonable maximum exposure

Figure 9-4
Total Excess Cancer Risks for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area



Note: Total PCBs non-cancer hazard quotients based on the immunological, integumantary, or neurological endpoints.

PCB = polychlorinated biphenyl; RME = reasonable maximum exposure

Figure 9-5a

Total PCB Non-cancer Hazard Quotients for the Adult Tribal RME Seafood Consumption Scenario

Feasibility Study

East Waterway Study Area

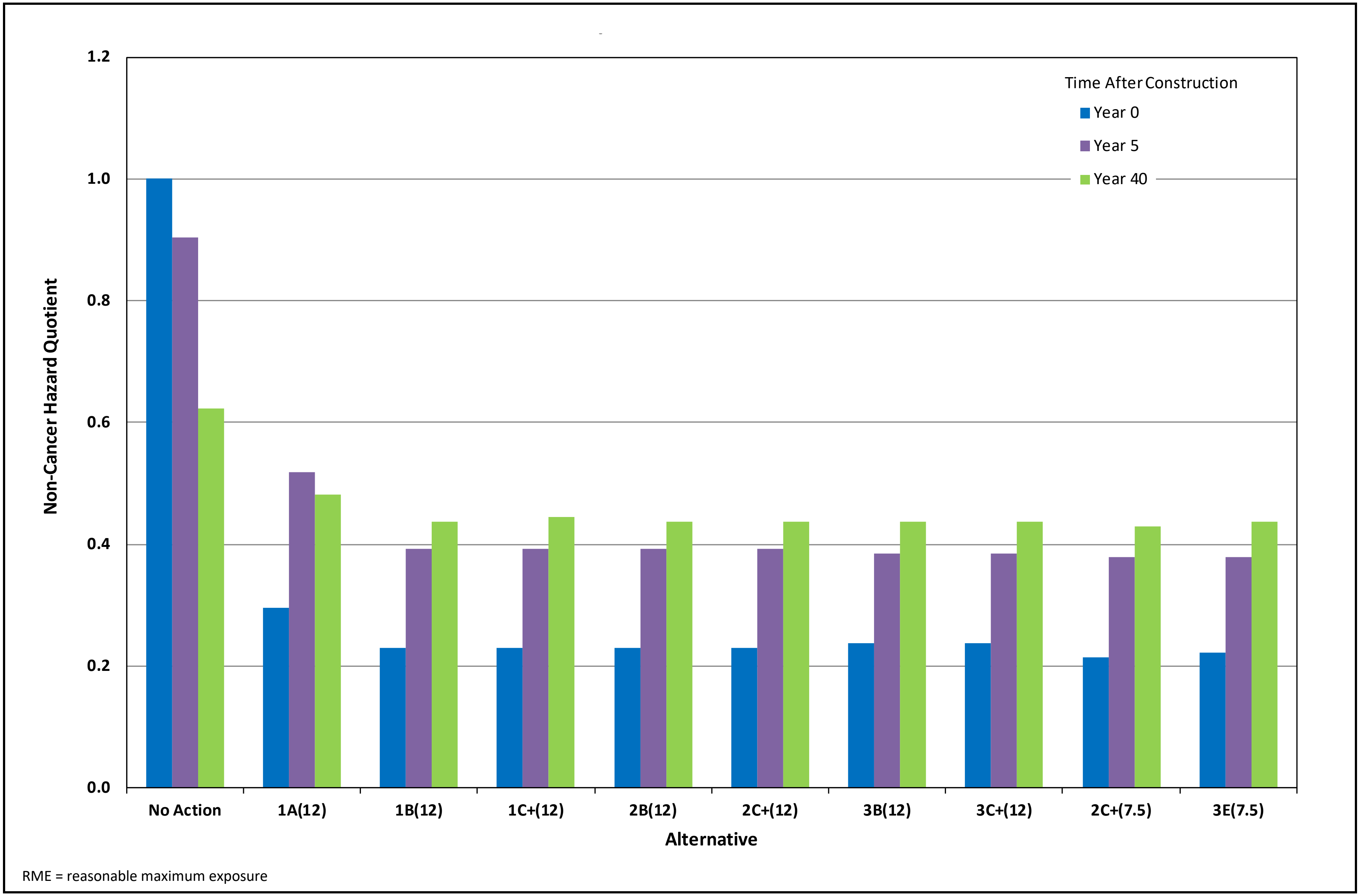
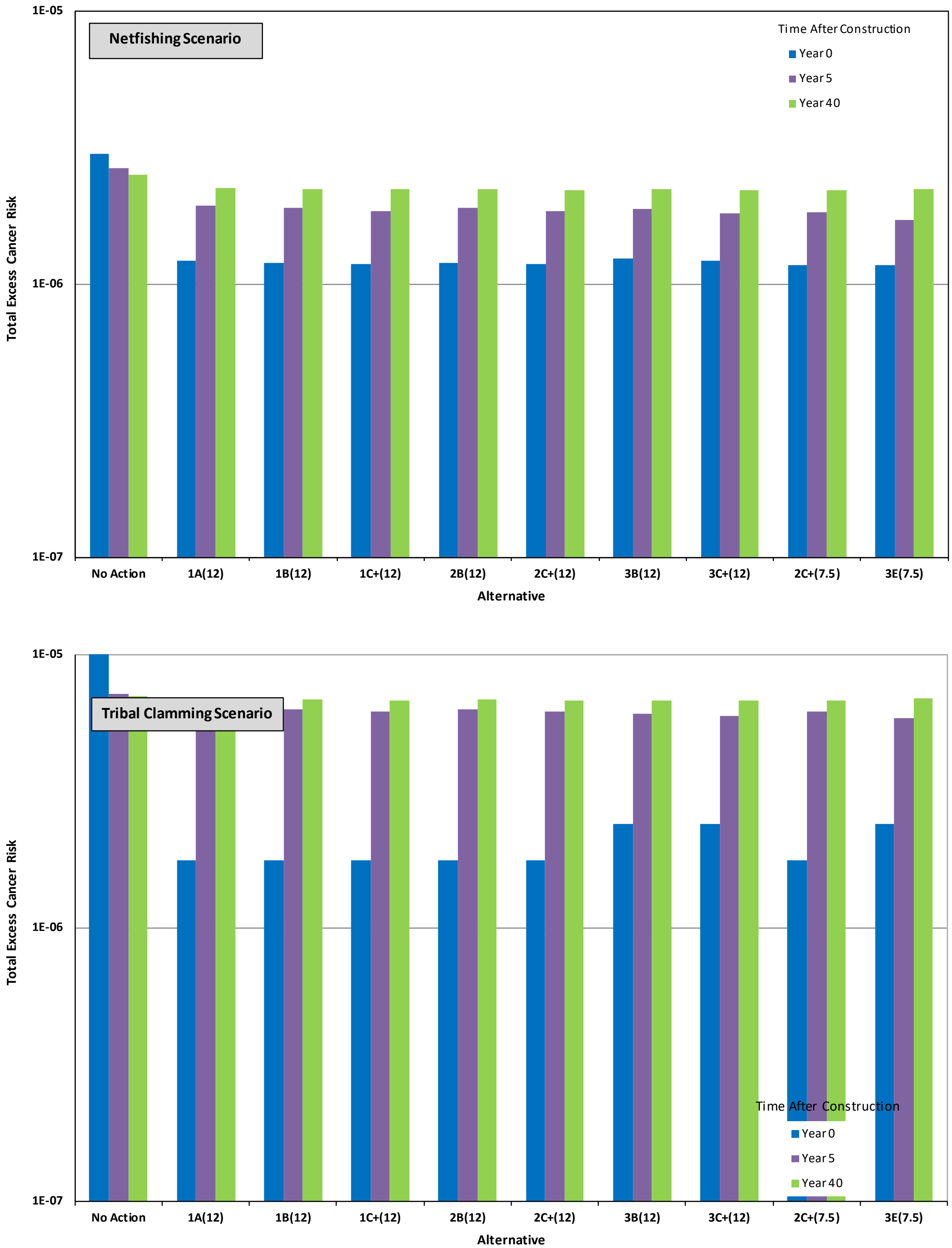


Figure 9-5b
Dioxin/Furans Non-cancer Hazard Quotients for the Adult Tribal RME Seafood Consumption Scenario
Feasibility Study
East Waterway Study Area



Note: Total direct contact excess cancer risks include arsenic risks for the netfishing scenario and the sum of arsenic and cPAHs risks for the tribal clamming scenario.

cPAH = carcinogenic polycyclic aromatic hydrocarbon
RME = reasonable maximum exposure

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Figure 9-6
Total Excess Cancer Risks for Netfishing and Tribal Clamming RME Scenarios
Feasibility Study
East Waterway Study Area

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2015.
3. Outfalls shown are for storm drain basins unless otherwise noted.

Criteria used for Contaminants of Concern (COC) Exceedance:
1,4 DCB - 3.1 mg/kg-OC
BEHP - 47 mg/kg-OC
Dioxin/Furan - 25 ng TEQ/kg dw
Mercury - 0.41 mg/kg dw

0 500 1,000
Scale in Feet

Figure 9-7a
Exceedances in PTM Model - Years 0 to 10
Feasibility Study
East Waterway Study Area

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Aerial photo is NAIP, 2015.
3. Outfalls shown are for storm drain basins unless otherwise noted.

Criteria used for Contaminants of Concern (COC) Exceedance:
1,4 DCB - 3.1 mg/kg-OC
BEHP - 47 mg/kg-OC
Dioxin/Furan - 25 ng TEQ/kg dw
Mercury - 0.41 mg/kg dw

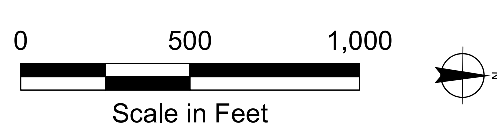

Figure 9-7b
Exceedances in PTM Model - Years 11 to 30
Feasibility Study
East Waterway Study Area

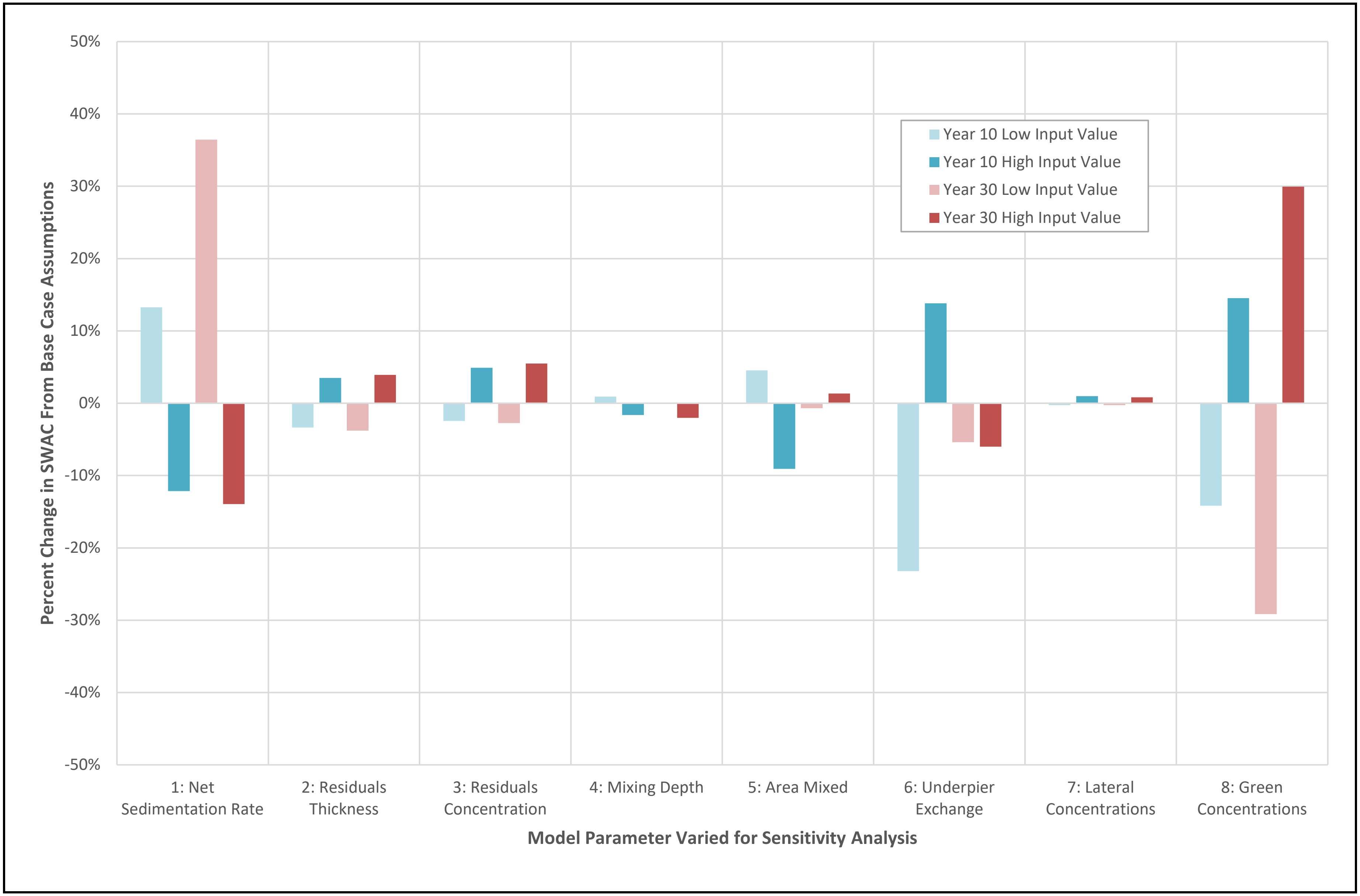

Figure 9-8a
Sensitivity Analysis, Relative Change in SWAC Values Compared to Base Case, Alternative 1A(12)
Feasibility Study
East Waterway Study Area

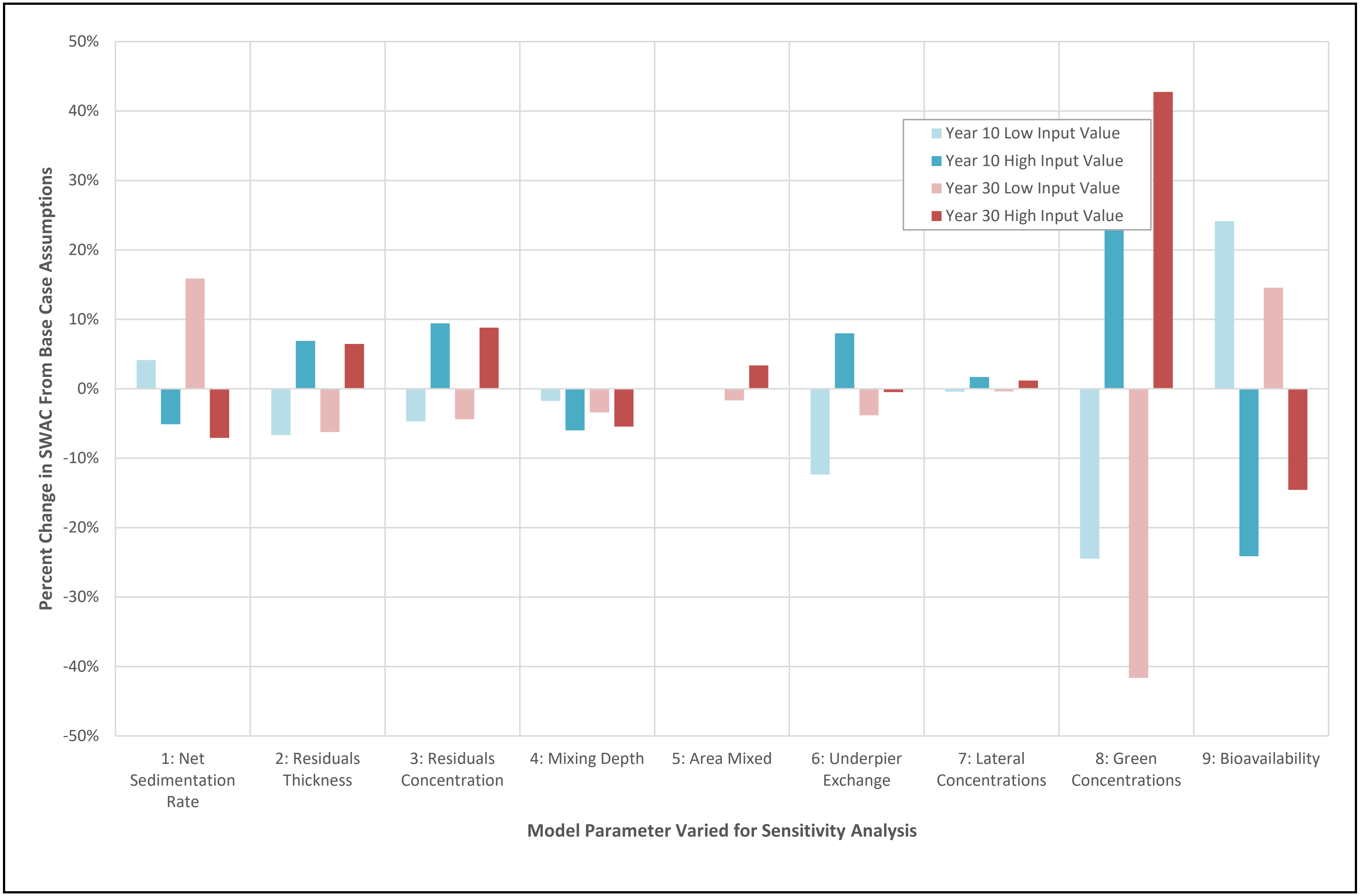

Figure 9-8b
Sensitivity Analysis, Relative Change in SWAC Values Compared to Base Case, Alternative 2B(12)
Feasibility Study
East Waterway Study Area

10 CERCLA COMPARATIVE ANALYSIS

This section performs the comparative evaluation of the alternatives based on CERCLA and the NCP, using the evaluation criteria presented in Section 9 to evaluate each alternative. Table 10-1 summarizes the comparative evaluation. The alternatives are first evaluated to assess whether they achieve or do not achieve the two threshold criteria. Then all remaining alternatives undergo detailed comparison using the five balancing criteria. The two modifying criteria will be evaluated later by EPA following public comment on its Proposed Plan. For the CERCLA balancing criteria, the table ranks the alternatives using a five-star ranking scale: one star (★) is the lowest rank and five stars (★★★★★) is the highest rank, relative to the other alternatives. The rationale for the star rankings are described in Table 10-1 and in Section 10.2 for each of the balancing criteria.

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria				Alternative: No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Threshold Criteria													
Overall Protection of Human Health and the Environment													
Long-term Effectiveness and Permanence	Magnitude and Type of Residual Risk	RAO 1 – Human Health (Seafood Consumption) [b, c]	Total PCBs and Dioxins/Furans	No Action is predicted to achieve total excess cancer risk of 5 × 10^{-4} (Adult Tribal RME), 9 × 10^{-5} (Child Tribal RME), and 2 × 10^{-4} (Adult API RME), and total PCB HQs of 11 (Adult Tribal RME), 23 (Child Tribal RME) and 9 (Adult API RME).	The action alternatives are predicted to achieve total excess cancer risks of 2 to 3 × 10^{-4} (Adult Tribal RME), 4 to 5 × 10^{-5} (Child Tribal RME), and 1 x 10^{-4} to 9 × 10^{-5} (Adult API RME). The alternatives are also predicted to achieve total PCBs non-cancer risks (based on immunological, integumentary, or neurological endpoints only, which are the highest of the non-cancer risks) of HQ = 4 to 5 (Adult Tribal RME), HQ = 9 to 12 (Child Tribal RME), and HQ = 4 to 5 (Adult API RME).								
		RAO 2 – Human Health (Direct Contact)	Arsenic	All alternatives are predicted to achieve a total excess cancer risk of less than 1 × 10^{-5}.For arsenic, all action alternatives achieve individual excess cancer risk of 2 x 10^{-6} for netfishing and 7 x 10^{-6} for clamming. Because the target risk threshold for arsenic is below natural background, the PRG is also used as a comparison: all action alternatives are predicted to meet the natural-background-based PRG following construction, but increase above the PRG in the long term due to incoming Green River concentrations. The No Action Alternative is not predicted to meet the arsenic PRG.									
		RAO 3 – Ecological Health (Benthic Organisms)	29 COCs [d]	Not expected to achieve.	Alternative 1A(12) is predicted to meet benthic PRGs in 99% of point locations 40 years following construction.	Alternatives 1B(12) through 3E(7.5) are predicted to meet benthic PRGs in 100% of point locations after construction completion.							
		RAO 4 – Ecological Health (Fish)	Total PCBs	HQ > 1.0 using the lower LOAEL TRV; HQ ≤ 1.0 using the higher LOAEL TRV.	All action alternatives are predicted to achieve HQ ≤ 1.0 for English sole and HQs ≤ 1.0 for brown rockfish for the higher TRV and 1.1 to 1.3 for the lower TRV (assumptions regarding water concentrations result in HQs slightly above 1.0) at year 40 following construction.								
	Controls	Engineering Controls		No controls assumed.	Relies primarily on removal (77 acres). Some reliance on partial removal and capping (13 acres), ENR-nav/partial removal and ENR-nav (16 acres), ENR-sill (2 acres), and MNR (13 acres underpier and low bridges).	Same as Alternative 1A(12) but with in situ treatment in underpier areas (12 acres) and ENR-sill under low bridges (1 acre), instead of MNR.	Same as Alternative 1B(12) but with diver-assisted hydraulic dredging prior to in situ treatment in some underpier areas (2 acres).	More reliance on removal than Alternatives 1A(12), 1B(12), and 1C+(12) (94 acres). Some reliance on partial removal and capping (13 acres), ENR-sill (3 acres), and in situ treatment (12 acres) in underpier areas.	Same as Alternative 2B(12) but with diver-assisted hydraulic dredging prior to in situ treatment in some underpier areas (2 acres).	More reliance on removal than Alternatives 1A(12) through 2C+(12) (100 acres). Some reliance on partial removal and capping (7 acres), ENR-sill (1 acre), and in situ treatment in underpier areas (12 acres).	Same as Alternative 3B(12) but with diver-assisted hydraulic dredging prior to in situ treatment in some underpier areas (2 acres).	More reliance on removal due to a lower RAL of 7.5 mg/kg OC (104 acres). Some reliance on partial removal and capping (13 acres), ENR-sill (3 acres), and in situ treatment (11 acres) and diver-assisted hydraulic dredging followed by in situ treatment (2 acres) in underpier areas.	Most reliance on removal (111 acres). Some reliance on partial removal and capping (7 acres), ENR-sill (1 acre), and diver-assisted hydraulic dredging followed by in situ treatment in underpier areas (13 acres).
		Institutional Controls			Institutional controls, including a notification, monitoring, and reporting program for areas of the EW and seafood consumption advisories and public outreach and education programs will be implemented to reduce seafood consumption exposures. Long-term monitoring, maintenance, and institutional controls are required for these alternatives.								
Short-term Effectiveness				No short-term impact because no actions assumed.	Short-term impacts increase with the length of construction (which vary from 9 to 13 years for the alternatives) and the amount of removal (810,000 to 1,080,000 cy) among the action alternatives. Alternatives 1B(12) through 3E(7.5) achieve RAOs immediately after construction completion, but will occur in a later calendar year for alternatives requiring a longer construction timeframe. Alternative 1A(12) meets all RAOs 39 years from the start of construction. PRGs for RAO 1 are not predicted to be achieved by any alternative. The time to achieve RAO 1 is uncertain, but all active alternatives will reach similar risk levels, except Alternative 1A(12), which may have greater uncertainty associated with MNR. See details on Short-term Effectiveness under Balancing Criteria.								

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

<table>
<tr><th colspan="2" rowspan="2">Evaluation Criteria</th><th colspan="11">Alternative</th></tr>
<tr><th>No Action</th><th>1A(12)</th><th>1B(12)</th><th>1C+(12)</th><th>2B(12)</th><th>2C+(12)</th><th>3B(12)</th><th>3C+(12)</th><th>2C+(7.5)</th><th>3E(7.5)</th></tr>
<tr><td colspan="2">Summary of Overall Protection of Human Health and the Environment</td><td>Does not provide adequate overall protection to human health and the environment.</td><td colspan="9">The action alternatives achieve overall protection of human health and the environment by relying primarily on removal of contaminated sediment from the EW. The action alternatives vary primarily in the remedial approach used to remediate sediment in underpier areas. All underpier technologies require engineering controls, including diver-assisted hydraulic dredging, which cannot completely remove sediment due to riprap, debris, and structural supports. All alternatives require institutional controls to fully achieve protectiveness. Longer construction periods and greater removal volumes result in proportionately greater short-term impacts.</td></tr>
<tr><td colspan="12">Compliance of ARARs</td></tr>
<tr><td rowspan="4">MTCA/SMS</td><td>Human Health – Seafood Consumption (RAO 1)</td><td>Not expected to comply.</td><td colspan="9">The action alternatives are not likely to meet all natural background-based PRGs. If EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs, EPA may adjust the cleanup level upward to the CSL, which could be attained in a reasonable restoration timeframe, consistent with the substantive requirements of SMS (see Sections 4.3.1 and 9.1.1.2), or waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).</td></tr>
<tr><td>Human Health – Direct Contact (RAO 2)</td><td>Predicted to comply within 20 years by achieving the SMS background level for arsenic.</td><td colspan="9">All action alternatives are expected to comply immediately following construction by achieving the SMS background level for arsenic.</td></tr>
<tr><td>Ecological Health – Benthic Organisms (RAO 3)</td><td>Not expected to comply.</td><td>Alternative 1A(12) is predicted to achieve RAO 3 PRGs 39 years from the start of construction.</td><td colspan="8">Alternatives 1B(12) through 3E(7.5) are predicted to achieve RAO 3 PRGs immediately following construction.</td></tr>
<tr><td>Ecological Health - Higher Trophic Level Species (RAO 4)</td><td>Predicted to comply within 10 years (English sole) to 25 years (brown rockfish).</td><td colspan="9">All action alternatives are predicted to comply by achieving the RAO 4 PRGs immediately following construction.</td></tr>
<tr><td colspan="2">Surface Water Quality Standards</td><td colspan="10">No active remedial measures are technically feasible or anticipated expressly for the water column, although significant water quality improvements are anticipated from sediment remediation and additional source control measures. It is not anticipated that any alternative can 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 (e.g., total PCBs and arsenic). If long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA may determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).</td></tr>
<tr><td colspan="2">Achieve Threshold Criteria?</td><td>No</td><td colspan="9">Yes; however, one or more ARAR waivers may be required.</td></tr>
</table>

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria			Alternative										
			No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Balancing Criteria													
Long-term Effectiveness and Permanence													
Magnitude of Residual Risk	Long-term Risk Outcomes		Does not achieve all.	See the risk outcomes for Magnitude and Type of Residual Risk above. The action alternatives achieve similar risk outcomes, with Alternative 1A(12) slightly higher for some risks.									
	Areas (acres; of 157 acres in the EW)[e]	Removal (open-water)	NA	77	77	77	94	94	100	100	104	111
		Partial removal/cap	NA	13	13	13	13	13	7	7	13	7
		Partial removal and ENR-nav, and ENR-nav	NA	16	16	16	NA	NA	NA	NA	NA	NA
		ENR-sill	NA	2	3	3	3	3	1	1	3	1
		MNR	NA	13	NA	NA	NA	NA	NA	NA	NA	NA
		In situ treatment	NA	NA	12	10	12	10	12	10	11	NA
		Diver-assisted hydraulic dredging followed by in situ treatment (underpier areas)	NA	NA	NA	2	NA	2	NA	2	2	13
		No action (area with concentrations < RALs for the action alternatives)	157	36	36	36	36	36	36	36	25	25
	Post-construction number of core stations remaining > CSL (of 76 cores in the EW)[f]	Partial dredging and capping	76	8	8	8	8	8	5	5	8	5
		Partial removal and ENR-nav, and ENR-nav		0	0	0	Not used	Not used	Not used	Not used	Not used	Not used
		ENR-sill		1	1	1	1	1	0	0	1	0
		MNR		0	Not used	Not used	Not used	Not used	Not used	Not used	Not used	Not used
		In situ treatment		Not used	0	0	0	0	0	0	0	Not used
		No action		2	2	2	2	2	2	2	2	2
	Summary of residual risks (modeled long-term risks and remaining subsurface contaminated sediment)		Highest long-term risks; most contaminated sediment remaining on site.	Slightly higher long-term risks than all active alternatives, moderate contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, moderate contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, moderate contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.	Lowest long-term risks among the active alternatives, low contaminated sediment remaining on site.
Adequacy and Reliability of Controls	Area requiring monitoring and maintenance (acres)	Moderate level of effort (partial dredging and capping)	No controls assumed.	13	13	13	13	13	7	7	13	7
		Higher level of effort (partial removal and ENR-nav, ENR-nav, ENR-sill, MNR, in situ treatment)		31	31	29	15	13	13	11	14	1
	Institutional Controls			The action alternatives require an Institutional Control Implementation and Assurance Plan with: 1) seafood consumption advisories, public outreach, and education programs; 2) review of in-water construction permit applications, waterway uses, and notification of users; and 3) designation of RNAs and other forms of notification and controls for areas with residual contamination to ensure performance of the remedy.									
Long-term Effectiveness and Permanence Ranking Guide			*The alternatives are ranked relative to other alternatives, with five stars representing the most effective in the long term and most permanent, and one star representing the least effective in the long term and least permanent. The ranking considers the metrics above, summarized as the following two that are considered equally: 1) the magnitude and type of residual risk remaining in the long term, including the risk outcomes and the area with remaining subsurface contamination; and 2) adequacy and reliability of engineering controls, considering the area requiring monitoring and maintenance.*										

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria	Alternative									
	No Action	**1A(12)**	**1B(12)**	**1C+(12)**	**2B(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**2C+(7.5)**	**3E(7.5)**
Summary of Long-term Effectiveness and Permanence	*Least effective and permanent compared to the other alternatives.*	*1A(12) achieves similar risk as all action alternatives* *In open water areas, 1A(12) relies primarily on removal and also includes partial removal and capping, partial removal and ENR, and ENR.* *Underpier, 1A(12) relies on MNR.* *1A(12) has less reliable underpier controls and open-water controls, compared to the other alternatives.*	*1A(12) achieves similar risk as all action alternatives* *In open water areas, 1B(12) is the same as 1A(12).* *Underpier, 1B(12) relies on in situ treatment.* *1B(12) has more reliable underpier controls than 1A(12) and slightly less reliable open-water controls than 2B(12) through 3E(7.5)*	*1A(12) achieves similar risk as all action alternatives* *In open water areas, 1C+(12) is the same as 1A(12).* *Underpier, 1C+(12) relies on limited removal plus in situ treatment* *1C+(12), has similarly reliable underpier controls as 1B(12), and slightly less reliable open-water controls than 2B(12) through 3E(7.5).*	*1A(12) achieves similar risk as all action alternatives* *In open water areas, 2B(12) is similar to 1A(12) but with no partial removal and ENR-nav or ENR-nav(more removal).* *Underpier, 2B(12) relies on in situ treatment.* *By relying almost exclusively on removal and capping, 2B(12) is considered highly permanent.*	*1A(12) achieves similar risk as all action alternatives* *In open water areas, 2C+(12) is the same as 2B(12).* *Underpier, 2C+(12) relies on limited removal plus in situ treatment* *By relying almost exclusively on removal and capping, 2C+(12) is considered highly permanent.*	*1A(12) achieves similar risk as all action alternatives* *In open-water areas, 3B(12) is similar to 2B(12) but with capping (more removal)* *Underpier, 2B(12) relies on in situ treatment.* *By relying almost exclusively on removal and capping, 3B(12) is considered highly permanent.*	*1A(12) achieves similar risk as all action alternatives* *In open water areas, 3C+(12) is the same as 3B(12).* *Underpier, 3C+(12) relies on limited removal plus in situ treatment* *By relying almost exclusively on removal and capping, 3C+(12) is considered highly permanent.*	*1A(12) achieves similar risk as all action alternatives* *In open water areas, 2C+(7.5) is the same as 2B(12) but with a slightly smaller no action area (more removal).* *Underpier, 2C+(7.5) relies on limited removal plus in situ treatment* *2C+(7.5) is considered similarly permanent to 2C+(12) because the lower RAL remediates areas of low contaminant concentrations.*	*1A(12) achieves similar risk as all action alternatives* *In open water areas, 3E(7.5)+(7.5) is the same as 3B(12) but with a slightly smaller no action area (more removal).* *Underpier, 3E(7.5) relies on removal plus in situ treatment* *3E(7.5) is considered similarly permanent to 2C+(7.5) because diver-assisted hydraulic dredging cannot remove all contaminated sediment on underpier structured slopes.*
Ranking [a] for long-term effectiveness and permanence	★	★★★	★★★★	★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Reduction of Toxicity, Mobility, or Volume Through Treatment										
In situ treatment area (acres)	NA	NA	12	12	12	12	12	12	13	13
Summary of Reduction of Toxicity, Mobility, or Volume Through Treatment	*No treatment.*	*No treatment.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*	*In situ treatment in underpier areas.*
Reduction of Toxicity, Mobility, or Volume Through Treatment Ranking Guide	*The alternatives are ranked relative to the total remediation area in the waterway, with five stars representing the use of extensive in situ treatment among the alternatives, and one star representing no use of in situ treatment. Although none of the alternatives employ in situ treatment extensively in the waterway, the highest-ranked alternative is given five stars.*									
Ranking [a] for reduction of toxicity, mobility, or volume through treatment	★	★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria				No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Short-term Effectiveness													
Protection of Human Health and the Environment During Construction	Period of effects to human health and the environment (construction timeframe; years) [g]			NA	9	9	9	10	10	10	10	11	13
	Transportation impacts (train/truck/barge; 1,000 miles)			NA	72 / 126 / 13	76 / 126 / 13	77 / 126 / 13	84 / 122 / 13	85 / 122 / 13	89 / 115 / 13	89 / 114 / 13	94 / 126 / 14	100 / 118 / 14
	Diver-assisted dredging (hazardous work duration; diver years)			NA	NA	NA	2	NA	2	NA	2	2	12
	Habitat area shallower than -10 feet MLLW impacted by dredging or capping in open-water areas (acres)			NA	4.1	4.1	4.1	4.1	4.1	5.8	5.8	4.7	6.6
	Depleted natural resources (material placement volume; cy)			NA	290,000	290,000	290,000	280,000	280,000	270,000	270,000	290,000	270,000
	Total removal volume / Consumed landfill capacity (cy) [h]			NA	810,000 / 970,000	810,000 / 970,000	820,000 / 980,000	900,000 / 1,080,000	910,000 / 1,090,000	960,000 / 1,150,000	960,000 / 1,150,000	1,010,000 / 1,210,000	1,080,000 / 1,300,000
	Air quality impacts (CO_2 / PM_{10} emissions; metric tons)			NA	16,000 / 5.4	16,000 / 5.6	16,000 / 5.9	17,000 / 6.1	18,000 / 6.3	18,000 /6.4	18,000 / 6.6	19,000 / 7.0	23,000 / 8.3
	Energy consumption (MJ)			NA	1.1×10^8	1.2×10^8	1.2×10^8	1.2×10^8	1.2×10^8	1.3×10^8	1.3×10^8	1.3×10^8	1.4×10^8
	Carbon footprint (acre-years)[i]			NA	3,800	3,800	3,800	4,000	4,300	4,300	4,300	4,500	5,400
Time to Achieve RAOs (Years from the Start of Construction)[j]	RAO 1 [k]	Total PCBs	10^{-4} Cancer Risk for Adult Tribal RME	35	9	9	9	10	10	10	10	11	13
			10^{-5} Cancer Risk for Child Tribal RME	Does not achieve.	34	9	9	10	10	10	10	11	13
			10^{-4} Cancer Risk for Adult API RME	0 (achieves at baseline conditions or start of construction)									
			10^{-5} Cancer Risk for Adult API RME	Does not achieve.	Not predicted to achieve.								
			Natural background PRG	Does not achieve.	Not predicted to achieve.								
		Dioxins/ Furans	10^{-4} Cancer Risk for Adult Tribal RME	0 (achieves at baseline conditions or start of construction)									
			10^{-5} Cancer Risk for Child Tribal RME	0 (achieves at baseline conditions or start of construction)									
			10^{-4} Cancer Risk for Adult API RME	0 (achieves at baseline conditions or start of construction)									
			10^{-5} Cancer Risk for Adult API RME	0 (achieves at baseline conditions or start of construction)									
			Natural background-based PRGs	Does not achieve.	Not predicted to achieve.								
	RAO 2[l]	Arsenic	Netfishing (site-wide)	Does not achieve.	9	9	9	10	10	10	10	11	13
			Clamming Areas	Does not achieve.	9	9	9	10	10	10	10	11	13
	RAO 3	29 COCs [d]		Not expected to achieve all PRGs.	39 [m]	9	9	10	10	10	10	11	13
	RAO 4	Total PCBs	English Sole	10	9	9	9	10	10	10	10	11	13
			Brown Rockfish	25	9	9	9	10	10	10	10	11	13
Short-term Effectiveness Ranking Guide				*The alternatives are ranked relative to each other, with five stars representing the most effective in the short term, and one star representing the least effective in the short term. The ranking considers the metrics above, summarized as the following three categories, which are considered in equal proportion: 1) community and worker protection during construction, which includes the duration of hazardous work (diver-assisted dredging); 2) environmental impacts from construction, including as a result of dredge releases, transportation, consumed landfill capacity, air emissions, energy consumption, and carbon footprint during implementation; and 3) the time to achieve RAOs (as a measure of the residual risk that is present on site until the RAOs are met).*									

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria	Alternative									
	No Action	**1A(12)**	**1B(12)**	**1C+(12)**	**2B(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**2C+(7.5)**	**3E(7.5)**
Summary of Short-term Effectiveness	*No construction impacts.* *Not predicted to achieve RAOs.*	*Lowest construction impacts of the action alternatives.* *The longest time to achieve RAOs of the action alternatives.*	*1B(12) has low construction impacts.* *The shortest time to achieve RAOs compared to the other action alternatives.*	*1C+(12) is similar to 1B(12) but with additional construction impacts and risks associated with diver-assisted hydraulic dredging alternatives.* *Shortest time to achieve RAOs compared to the other action alternatives.*	*2B(12) has relatively low construction impacts (1 year longer than 1B(12)).* *Slightly longer time (1 year longer) to achieve RAOs compared to 1B(12) and 1C+(12).*	*2C+(12) is similar to 2B(12) but with additional construction impacts and risks associated with diver-assisted hydraulic dredging alternatives.* *Slightly longer time to achieve RAOs (1 year longer) compared to 1B(12) and 1C+(12).*	*3B(12) has moderate impacts.* *Slightly greater time to achieve RAOs compared to 1B(12) and scores slightly lower.*	*3C+(12) is similar to 3B(12) but with additional construction impacts and risks associated with diver-assisted hydraulic dredging alternatives.* *Slightly longer time to achieve RAOs (1 year longer) compared to 1B(12) and 1C+(12).*	*2C+(7.5) is similar to 2C+(12) but with additional construction impacts due to a longer construction duration.* *Longer time to achieve RAOs (2 years longer) compared to 1B(12) and 1C+(12).*	*3E(7.5) has the largest construction impacts from the most removal and risks associated with extensive diver-assisted hydraulic dredging.* *Longest time to achieve RAOs behind 1A(12) and the No Action Alternative.*
Ranking [a] for short-term effectiveness	★	★★	★★★★★	★★★★	★★★★	★★★	★★★★	★★★	★★	★
Implementability										
Technical Implementability	No construction (beyond source control implemented under different programs).	Shortest construction period. Lowest potential for difficulties and delays and impacts to EW tenants and users. No technical challenges associated with implementing MNR in underpier areas for Alternative 1A(12).	Shortest construction period. Low potential for difficulties and delays and impacts to EW tenants and users. Few technical challenges associated with implementing ENR for Alternative 1B(12).Technical challenges associated with the use of in situ treatment employed in underpier areas.	Shortest construction period. Low potential for difficulties and delays and impacts to EW tenants and users. Significant technical challenges and safety concerns associated with diver-assisted hydraulic dredging. Few technical challenges associated with implementing ENR for 1C+(12). Technical challenges associated with in situ treatment employed in underpier areas.	Moderate construction period and moderate potential for difficulties and delays and impacts to EW tenants and users. Technical challenges associated with in situ treatment in underpier areas.	Moderate construction period and moderate potential for difficulties and delays. Significant technical challenges and safety concerns associated with diver-assisted hydraulic dredging. Technical challenges associated with in situ treatment employed in underpier areas.	Moderate construction period and moderate potential for difficulties and delays. Technical challenges associated with the use of in situ treatment employed in underpier areas.	Moderate construction period and moderate potential for difficulties and delays. Significant technical challenges and safety concerns associated with diver-assisted hydraulic dredging. Technical challenges associated with in situ treatment employed in underpier areas.	Moderate construction period and moderate potential for difficulties and delays. Significant technical challenges and safety concerns associated with diver-assisted hydraulic dredging. Technical challenges associated with in situ treatment employed in underpier areas.	Longest construction period. Highest potential for difficulties and delays and impact to EW tenants and users. Significant technical challenges and safety concerns associated with multiple years of diver-assisted hydraulic dredging. Technical challenges associated with in situ treatment employed in underpier areas.

Table 10-1
Comparative Evaluation and Ranking of Alternatives[a]

Evaluation Criteria	Alternative									
	No Action	**1A(12)**	**1B(12)**	**1C+(12)**	**2B(12)**	**2C+(12)**	**3B(12)**	**3C+(12)**	**2C+(7.5)**	**3E(7.5)**
Administrative Implementability	No contingency actions (beyond source control implemented under different programs).	Lower overall scope. Largest potential for contingency actions in 31 acres of partial removal and ENR-nav, ENR-nav, ENR-sill, and MNR. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Low overall scope. Similar potential for contingency actions as 1A(12) in 31 acres of partial removal and ENR-nav, ENR-nav, ENR-sill, and in situ treatment. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Low overall scope. Similar potential for contingency actions as 1A(12) in 29 acres of partial removal and ENR-nav, ENR-nav, ENR-sill, and in situ treatment. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Moderate overall scope. Potential contingency actions in 3 acres of ENR-sill, and 12 acres of in situ treatment. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Moderate overall scope. Potential contingency actions in 3 acres of ENR-sill and 10 acres of in situ treatment. Reauthorization of a small part of the federal navigation channel (Shallow Main Body – South) will be required.	Moderate overall scope. Potential contingency actions in 1 acre of ENR-sill and 12 acres of in situ treatment.	Moderate overall scope. Potential contingency actions in 1 acre of ENR-sill and 10 acres of in situ treatment.	Moderate to high overall scope. Potential contingency actions in 3 acres of ENR-sill and 11 acres of in situ treatment.	Largest overall scope of cleanup. Least potential for contingency actions in 1 acre of ENR-sill.
Implementability Ranking Guide	*The alternatives are ranked relative to each other, with five stars representing the most implementable, and one star representing the least implementable. The ranking considers the following primary metrics considered equally: 1) technical implementability, with the key differentiating factor being the approach to remediating the technically challenging sediments under the piers; and 2) administrative implementability, with the key differentiating factor being the overall complexity of the cleanup, which accounts for annual challenges of permitting, fisheries coordination, Port tenant and shipping vessel coordination, and staging. Contingency actions are also included in the ranking for implementability; however, this is considered a secondary metric which is weighted less in the overall ranking because contingency actions are potential conditions only.*									
Summary of Implementability	*Most implementable of the alternatives.*	*Most implementable of the action alternatives.*	*Less implementable compared to 1A(12) due to challenges with in situ treatment in underpier sediment.*	*Less implementable compared to 1B(12) due to challenges with diver-assisted hydraulic dredging in addition to also implementing in situ treatment.*	*Similar implementability as 1B(12) due to similar technology challenges in open-water and underpier areas.*	*Similar implementability as 1C+(12) due to similar technology challenges in open-water and underpier areas.*	*Similar implementability as 1B(12) due to similar technology challenges in open-water and underpier areas.*	*Similar implementability as 1C+(12) due to similar technology challenges in open-water and underpier areas.*	*Similar implementability as 1C+(12) due to similar technology challenges in open-water and underpier areas.*	*Least implementable of the alternatives due to extensive diver-assisted hydraulic dredging and large scope of open-water remediation.*
Ranking [a] for implementability	★★★★★	★★★★	★★★	★★	★★★	★★	★★★	★★	★★	★
Costs										
Costs Ranking Guide	*The No Action Alternative is ranked five stars as the least expensive. The action alternatives are ranked relative to each other, with four stars representing the least expensive, and one star representing the most expensive. The action alternatives are grouped based on ranges of costs, using intervals of $30 million each (i.e., $240 to $270 million, $270 to $300 million, $300 to $330 million, and more than $330 million).*									
Total Costs ($)	950,000	256,000,000	264,000,000	277,000,000	284,000,000	297,000,000	298,000,000	310,000,000	326,000,000	411,000,000
Ranking [a] for costs	★★★★★	★★★★	★★★★	★★★	★★★	★★★	★★★	★★	★★	★

Notes:

a. The alternatives are ranked from one star to five stars relative to the other alternatives, and also considering the metrics used to evaluate the criterion, with more stars indicating a more favorable ranking. See Sections 10.2.1.3, 10.2.2, 10.2.3.4, 10.2.4.1, and 10.2.5 for guidance on interpretation of rankings.

b. Risk estimates are based on the use of the total PCB and dioxin/furan SWACs in the FWM and BSAF, respectively. Risks due to cPAHs, which are based on clam consumption, are not included because cPAHs in clam tissue were not calculated due to the poor relationship between sediment and tissue values in the SRI dataset.

c. See Tables 9-5a and 9-5b for other RME risk scenarios.

d. For FS purposes, achievement of RAO 3 is based on at least 98% of predicted surface sediment locations achieving PRGs for all 29 benthic COCs. Compliance with SMS benthic criteria will be determined based on SMS requirements. Predictive modeling was not conducted for the No Action Alternative for compliance of RAO 3; therefore, the percentage of surface sediment locations below PRGs are presented for existing conditions (see Table 9-3).e. In the context of long-term effectiveness and permanence, different technologies have different magnitude of residual risk because they leave different amounts of contamination on site and use different engineering controls.

f. The total number of core stations is 146; 1 in the underpier areas and 145 in open-water areas. All 76 cores with one or more CSL exceedances are in open-water areas. The number of core stations post-construction remaining exceeding the SQS (but below CSL) are presented in Table 9-10.

g. Construction timeframe rounded up to the nearest year, assuming some concurrent removal and material placement (see Table 8-6 for details). As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15); thus, the upper end of the number of work days in a construction season could increase to around 150 days/season, reducing the total number of years of construction by about 2 years for all action alternatives. However, the total number of construction days and associated construction impacts would remain unchanged.

h. The landfill capacity consumed is proportional to the volume of dredged material removed and disposed of in the landfill (assuming a 20% bulking factor).

i. One acre-year represents the amount of CO_2 sequestered by 1 acre of Douglas fir forest for 1 year. Carbon footprint in units of acre-years is appropriate to compare the alternatives differences in CO_2 releases over the entire project.

j. Some RAO metrics are achieved immediately after construction. If a longer construction window is allowed (see footnote above), the number of years of construction and corresponding time to achieve the RAOs would decrease by about 2 years for all action alternatives (see Section 9.1.2.3).

k. The orders of magnitude risk values presented for time to achieve RAOs were selected to most differentiate the alternatives. Alternative compliance is based on attaining the PRGs or target risk thresholds. Times to achieve RAOs could be reduced if a longer construction window is allowed, as the total number of years of construction could decrease by 2 years for all action alternatives (see Section 9.1.2.3).

l. Achievement of RAO 2 is based on meeting PRG (arsenic). All action alternatives are predicted to meet the arsenic RAO 2 PRG of 7 mg/kg dw following construction, but increase above the PRG in the long term due to the Green River input concentrations (Section 9.15.1.2). All alternatives, including the No Action Alternative, may meet the PRG in the long term, depending on actual site conditions.

m. Time to achieve RAO 3 PRG based on total PCBs; all other benthic risk driver COCs achieve PRGs immediately after construction completion.

Abbreviations:

API – Asian Pacific Islander
ARAR – applicable or relevant and appropriate requirements
BSAF – Biota-Sediment Accumulation Factors
CO_2 – carbon dioxide
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
cy – cubic yards
CSL – cleanup screening level
dw – dry weight
ENR-nav – enhanced natural recovery used in the navigation channel or berthing areas
ENR-sill – enhanced natural recovery used in the sill reach
EPA – U.S. Environmental Protection Agency
EW – East Waterway
FS – Feasibility Study
FWM – Food Web Model
HQ – hazard quotient
LOAEL – lowest observed adverse effect level
mg/kg – milligrams per kilogram
MLLW – mean lower low water
MNR – monitored natural recovery
MJ – megajoule
MTCA – Model Toxics Control Act
NA – not applicable
OC – organic carbon
PCB – polychlorinated biphenyl
PM_{10} – particulate matter less than 10 microns in diameter
PRG – preliminary remediation goal
RAL – remedial action level
RAO – remedial action objective
RME – reasonable maximum exposure
RNA – restricted navigation areas
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SRI – Supplemental Remedial Investigation
SWAC – spatially-weighted average concentration
TRV – toxicity reference value

10.1 Threshold Criteria

The two threshold criteria are:

1. Overall protection of human health and the environment
2. Compliance with ARARs

10.1.1 Overall Protection of Human Health and Environment

This criterion addresses whether an alternative provides adequate protection of human health and the environment. EPA guidance (1988) states that the assessment of overall protection draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and short-term effectiveness, as discussed in the following sections.

10.1.1.1 Overall Protection – Long-term Effectiveness and Permanence

For this evaluation, long-term effectiveness and permanence have two major aspects, as follows:

1. The magnitude and type of residual risks to humans, wildlife, and the benthic community
2. Engineering and institutional controls used to mitigate those residual risks

Magnitude and Type of Residual Risks

As discussed in Section 4, RAOs were developed for protection of people who use the waterway, the benthic community, fish, and wildlife. Table 10-1 summarizes the predicted residual risks achieved for each alternative for each RAO.

The No Action Alternative is predicted to achieve RAO 4 but not RAOs 1, 2, or 3. The action alternatives are predicted to achieve all the RAOs.

While the action alternatives are not predicted to achieve the natural background-based PRGs for RAO 1 for total PCBs or dioxins/furans, they are predicted to achieve similar reductions in risks. For example, all action alternatives, with the exception of Alternative 1A(12), are predicted to achieve a residual total excess cancer risk of 2×10^{-4} for the Adult Tribal seafood consumption RME scenario, 4×10^{-5} for the Child Tribal seafood consumption RME scenario, and 9×10^{-5} for the Adult API RME scenario 40 years after construction completion. Alternative 1A(12) is predicted to achieve 3×10^{-4}, 5×10^{-5}, and 1×10^{-4} for the three scenarios, respectively. In addition, the residual non-cancer HQs for total PCBs[149] are predicted to be similar for all action alternatives, 4 to 5 for the Adult Tribal RME scenario, 9 to 12 for the Child Tribal RME scenario, and 4 to 5 for the Adult API RME scenario (see Tables 9-5a through 9-5d).

For RAO 2, all alternatives are predicted to achieve a total excess cancer risk of less than 1×10^{-5}. For arsenic, the action alternatives are predicted to meet the natural-background-based PRG following construction, but increase above the PRG in the long term due to incoming Green River concentrations. The No Action Alternative is not predicted to meet the arsenic PRG (see Tables 9-2 and 9-6).

For RAO 3, the No Action Alternative is not expected to achieve the benthic PRGs. Alternative 1A(12) is predicted to meet benthic PRGs in 99% of point locations 40 years following construction. Alternatives 1B(12) through 3E(7.5) are predicted to meet benthic PRGs in 100% of point locations after construction completion (see Table 9-3).

For RAO 4, the No Action Alternative does not achieve an HQ less than 1.0 using the lower LOAEL TRV, but does achieve an HQ less than 1.0 using the higher LOAEL TRV (see Table 9-7). The No Action Alternative is predicted to meet both PRGs within 25 years (see Table 9-1a). All action alternatives are predicted to achieve an HQ less than 1.0 for English sole (using either LOAEL TRV) and for brown rockfish (using the higher LOAEL TRV). An HQ ranging from 1.0 to 1.3 for brown rockfish is achieved using the lower LOAEL TRV (the HQ is greater than 1.0 because of influence of receiving water PCB concentrations; see Table 9-7). All action alternatives are predicted to meet the PRGs following construction (see Table 9-1a).

Adequacy and Reliability of Controls

Adequacy and reliability of controls includes the engineering and institutional controls used to limit and manage risks associated with contaminated sediments that remain for each alternative.

[149] Based on the immunological, integumentary, or neurological endpoints.

The No Action Alternative provides no engineering controls. The action alternatives rely primarily on dredging (64% to 94% of the remedial footprint depending on the alternative), followed by partial dredging and capping (5% to 11% of the remedial footprint depending on the alternative), and therefore employ important engineering controls. Table 10-1 provides the areas of capping, partial removal and ENR-nav/ENR-nav, ENR-sill, in situ treatment, diver-assisted hydraulic dredging, and MNR for the alternatives to approximate the area with subsurface contamination remaining following construction and to indicate the additional engineering controls (e.g., monitoring and maintenance) required for each area.

The reliability of engineering controls varies according to the remedial technology used. Mechanical dredging in open water areas is generally considered the most reliable technology over the long term because less contaminated sediment remains on site following remediation. Diver-assisted hydraulic dredging in underpier areas is considered less reliable because riprap, debris, and structural supports prevent sediment from being completely removed. Capping is considered very reliable over the long term because contaminated sediment is isolated below an engineered and monitored layer of material. ENR and in situ treatment, although designed for the conditions where they will be used, are considered less reliable because they depend on more complicated chemical and physical processes, such as sedimentation and contaminant adsorption. MNR has the lowest reliability because it relies entirely on the reduction of contaminated sediment concentrations through a combination of natural processes (e.g., physical, biological, and chemical). All remedial technologies include monitoring and potential contingency actions to increase their reliability over time.

The No Action Alternative provides no institutional controls beyond those that are currently in place (e.g., existing consumption advisories). All of the action alternatives would all have similar types of institutional controls, which would be adequate when coupled with outreach, education, and engineering controls (i.e., active remediation) that form the basis of these alternatives. Institutional controls are used to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. As discussed in Section 7.2.2, an ICIAP for the EW would include a notification, monitoring, and reporting program for areas of the EW where contamination remains in place to ensure the performance of the remedy. This program may include elements such as proprietary controls and designation of RNAs in order to prevent unconditioned or uncontrolled activities that could result in the release or exposure of buried contaminants to people or the environment. In addition, the ICIAP will include seafood consumption advisories and public outreach and education programs as necessary.

10.1.1.2 Overall Protection – Short-term Effectiveness

Overall protectiveness of the alternatives can also be discerned in the context of short-term effectiveness, which includes impacts during the construction phase (the time required to implement the remedy) and the time to achieve RAOs.

Alternatives with shorter construction periods and less total sediment removal translate into lower impacts to workers, the community, and the environment during implementation. Predicted impacts during construction include traffic, noise, worker injuries/fatalities, dredge material resuspension and releases, air pollutant emissions, natural resource depletion, physical disruption of aquatic habitat, and elevated fish and shellfish tissue contaminant concentrations (see Section 10.2.3). In general, the impacts from construction are greatest for dredging, relatively high for capping, and significantly reduced for ENR, in situ treatment, and MNR. Impacts are generally considered proportional to total construction time; however, short-term impacts to workers are expected to be larger for alternatives with diver-assisted hydraulic dredging due to the hazards associated with underpier, deep water work.

The No Action Alternative has no active remediation, and therefore, has no short-term impacts from construction activities beyond monitoring. All of the action alternatives have significant construction-related impacts that are necessary to remediate the EW (i.e., meet the RAOs) and maintain site uses. The action alternatives range from 9 years of construction and 810,000 cy of sediment removed from the waterway for Alternative 1A(12), to 13 years of construction and 1,080,000 cy of sediment removed for Alternative 3E(7.5).

While the No Action Alternative is not predicted to achieve all RAOs, all of the action alternatives are predicted to achieve RAOs. The action alternatives are predicted to achieve PRGs for RAOs 2 through 4 immediately following construction, with the exception of Alternative 1A(12), which is predicted to achieve RAO 3 in 39 years from the start of construction. In addition, all of the action alternatives achieve similar risk reductions toward meeting RAO 1, and the time to achieve RAO 1 is expected to be similar for any of the action alternatives.

10.1.1.3 Overall Protection Summary

The No Action Alternative does not provide adequate protection of human health and the environment, engineering controls, or institutional controls and does not achieve all of the RAOs; therefore, it does not achieve threshold criteria. All of the nine action alternatives are sufficiently effective in the short term and the long term to meet threshold requirements.

In the long term, the action alternatives achieve significant risk reduction using reliable remedial technologies, achieve the CERCLA risk range of 10^{-4} to 10^{-6}, and include monitoring and institutional controls to measure and ensure risk reduction.

In the short term, alternatives with larger removal volumes and longer construction times present proportionately greater risks to workers, the community, and the environment. Longer construction periods increase equipment and vehicle emissions, noise, and other resource use. Construction durations range from 9 to 13 years, due to the large scope of dredging for all alternatives. Most impacts due to construction vary proportionally with construction duration; however, short-term impacts to workers are expected to be larger for alternatives with diver-assisted hydraulic dredging due to the hazards associated with underpier, deep water work. The action alternatives are predicted to achieve PRGs for RAOs 2 through 4. None of the action alternatives achieve the natural background-based PRGs for RAO 1, but achieve similar risk reduction toward meeting RAO 1.

10.1.2 Compliance with ARARs

The two most important ARARs in terms of evaluating the alternatives are MTCA (statute and regulations) and state surface water quality standards and federal recommended water quality criteria.

MTCA Compliance

Part V of the SMS (WAC 173-204) is promulgated under MTCA and establishes requirements for remediation of contaminated sediment. The nine action alternatives have been developed to be compliant with SMS. In particular, SMS (WAC 173-204-560) provides rules for developing cleanup levels considering multiple exposure pathways, background concentrations, and PQLs. The PRGs were developed to be consistent with the rules for cleanup level determination in SMS, but without considering regional background as it has not been defined for this area (see Appendix A for additional details).

All of the action alternatives are expected to comply with MTCA/SMS standards for protectiveness of human health for direct contact (RAO 2), protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) through active remediation, and additional MNR for Alternative 1A(12) only. For protection of human health for seafood consumption (RAO 1), none of the action alternatives are predicted to achieve the natural background PRGs for PCBs or dioxins/furans, due to model input parameters that assume ongoing contribution of contaminants from diffuse nonpoint sources upstream of the EW. Although the SMS allows for use of a regional background-based cleanup level if it is not technically possible to meet and maintain natural background levels, regional background levels have not yet been established for the geographic area of the EW.

However, CERCLA compliance with MTCA/SMS ARARs may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are much lower than current model predictions, and PRGs identified in this FS are attained in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

Water Quality Standards Compliance

All of the alternatives must comply substantively with relevant and appropriate state water quality standards and any more stringent recommended federal surface water quality criteria upon completion of the remedial action, except to the extent that they may be formally waived by EPA. Dredging and construction projects previously implemented in the EW OU have complied with project-specific water quality certification requirements. Compliance with these or similar certification requirements can be expected regardless of the alternative selected, provided that dredging methods include BMPs to ensure that dissolved and suspended releases (e.g., of COCs and TSS) do not result in exceedances of water quality standards (EPA 2005; NRC 2007; USACE 2008b). Implementing multiple remedial actions simultaneously and in relatively close proximity to one another could increase the risk of violating short-term water quality requirements, a consideration that should be factored into project sequencing and production rate decisions. Careful planning, production rate controls, and the use of BMPs are warranted in all cases to reduce short-term water quality impacts.

Cleanup of sediments, along with source control actions, are expected to reduce concentrations of COCs, such as total PCBs, in the water column following cleanup actions. Other factors not related to releases from the site (e.g., inflow of river water from upstream, marine water from downstream, or aerial deposition of COCs from distant sources) also contribute to COC concentrations in water. Currently, Green River upstream and Elliott Bay downstream water concentrations appear to be above federal recommended human health water quality criteria for total PCBs and arsenic. If long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA will determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of TI in a future decision document (ROD Amendment or ESD).

Compliance with Other ARARs

The construction elements for the alternatives are similar in nature and scope to sediment remediation projects previously implemented in the Puget Sound region. It is therefore anticipated that all of the alternatives can be designed and implemented to comply with ARARs including the following:

- **Management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste).** These ARARs primarily concern the handling and disposal of materials. They may complicate implementation and add costs but should not influence whether an alternative is fundamentally viable.
- **Resource protection requirements (e.g., habitat preservation and mitigation).** These do not pose a fundamental obstacle to the design and implementation of the alternatives. In the short term, the benthic community within the intertidal and shallow subtidal habitat areas above -10 feet MLLW, which are critical habitats to outmigrating salmonids and important intertidal habitats, would be impacted during dredging and capping activities. In these areas, benthic organisms must recolonize in the biologically active zone and regain ecological functions following remediation.

CWA 404 dredge and fill requirements can be met for all alternatives. As with previous regional CERCLA sediment remediation projects, EPA would evaluate the selected alternative for substantive compliance with CWA 404(b)(1) and Rivers and Harbors Act Section 10 requirements. Specific design elements would ensure that these requirements are satisfied.

10.2 Balancing Criteria

The alternatives were compared using the five balancing criteria designated by CERCLA. The subsections below present the comparison.

10.2.1 Long-term Effectiveness and Permanence

This balancing criterion compares the relative magnitude and type of residual risk that would remain in the EW after remediation under each alternative. In addition, it assesses the extent and effectiveness of the controls that may be required to manage the residual risks from contamination remaining at the site after remediation (Section 9.1.2.1).

10.2.1.1 Magnitude and Type of Residual Risk

The alternatives were evaluated for two types of residual risks following cleanup. The first type is the risk predicted to remain on site from exposure to surface sediment contaminant concentrations after the completion of remediation and over time. The second type of residual risk is from contaminated sediments remaining in the subsurface after remediation (e.g., under caps or in areas remediated by ENR, in situ treatment, or MNR), which may be exposed in the future through disturbance.

Residual risks to humans, the benthic community, and fish from surface sediment COC concentrations after remediation were estimated and described in Section 9 and in Table 10-1. All of the alternatives, except the No Action Alternative, are predicted to achieve similar residual surface sediment COC concentrations and risk levels in the long term.

Evaluation of residual risks also considered the potential for exposure of subsurface contamination left in place following remediation. Mechanisms for deep disturbance of subsurface sediment including vessels maneuvering under typical and extreme operations, ship groundings, and operations such as pier maintenance activities, may occur on a recurring basis in a working industrial waterway like the EW. Most open-water areas, excluding areas with caps, will be potentially subject to propwash disturbances ranging from 0.5 to 5 feet. The majority of the EW could experience scour depths of 2 feet or greater under normal to extreme operating conditions, and such mixing, dependent on vessel operation areas, has been incorporated into the long-term performance modeling (Section 9.2.1). Another type of disturbance includes earthquakes, which could potentially expose subsurface contaminated sediment, but their impacts in the waterway would be minimal compared to potential for disturbance from upland liquefiable soils, slope failures, and spills that would impact the bed of the EW (Section 2.14.5).

All of the action alternatives emphasize removal of contaminated sediments, and thus, have a low potential for subsurface sediment to be exposed. Table 10-1 contains the following metrics, developed and presented in Section 9, that were used to compare the magnitude of subsurface contamination remaining in place and the potential for it to be exposed for each alternative:

- **Long-term Risk Outcomes:** Section 10.1.1.1 describes the long-term risk outcomes for the alternatives. All of the action alternatives achieve similar risk outcomes, with Alternative 1A(12) having slightly higher risks due to the use of MNR under the piers. In addition, the effectiveness of MNR is more uncertain than active remedial technologies. The other underpier technology options (i.e., the B, C+, and E alternatives) result in the same long-term risk outcomes and therefore, in situ treatment is as effective as underpier removal. In addition, there is no difference in long-term risk among the open-water technology options (i.e., the 1, 2, and 3 alternatives), or among the different RAL options (i.e., the (12) and (7.5) alternatives).
- **Area dredged in open-water and under piers:** Subsurface contaminated sediment is removed in these areas, as follows:
  - Alternatives 1A(12), 1B(12), and 1C+(12) perform removal over 77 to 79 acres of the EW
  - Alternatives 2B(12) and 2C+(12) perform removal over 94 to 96 acres of the EW
  - Alternatives 3B(12), 3C+(12), and 2C+(7.5) perform removal over 100 to 106 acres of the EW
  - Alternative 3E(7.5) performs removal over 124 acres of the EW
- **Area partially dredged and capped:** The risk of exposing contaminated subsurface sediment is relatively low in capped areas because the caps are engineered to remain structurally stable under location-specific conditions and provide a high degree of protectiveness. All action alternatives perform a similar degree of partial dredging and capping, ranging from 7 acres (Alternatives 3B(12), 3C+(12), and 3E(7.5)), to 13 acres (Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), and 2C+(7.5)).
- **In situ treatment, partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR:** Areas remediated by in situ treatment, partial removal and ENR-nav/ENR-nav, ENR-sill, or MNR have a higher potential for exposure of contaminated subsurface sediment as a result of disturbance, such as from propwash, than capped areas because, unlike caps, these technologies are not engineered to completely isolate subsurface contaminated sediments. In situ treatment is considered more permanent than partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR because in situ treatment permanently binds and reduces the bioavailability of hydrophobic organic compounds (e.g., PCBs) by an estimated 70% (see Section 7.2.7.1). Proposed in situ treatment, partial removal and

ENR-nav/ENR-nav, ENR-sill, and MNR areas represent a relatively small contribution (less than 20%) to the overall EW remedial footprint for alternatives: 29 to 31 acres for Alternatives 1A(12), 1B(12), and 1C+(12); 11 to 15 acres for Alternatives 2B(12), 2C+(12), 2C+(7.5), 3B(12), and 3C+(12); and 1 acre for Alternative 3E(7.5). However, the effect of exposure of subsurface contamination due to disturbance is anticipated to be minimal for these technologies for the following reasons:

- The majority of the remedial footprint area is addressed through removal technologies.
- Predictive modeling of impacts from disturbances indicates minimal effect to overall concentrations. Sediment mixing due to vessel scour has been incorporated into predictions of surface sediment concentrations in the FS (e.g., Table 9-1a). In scour areas (e.g., the navigation channel), the upper 2 feet of sediment is assumed to be mixed every 5 years in 50% of the area (Section 5). In underpier areas, sediment is assumed to be mixed with a portion exchanged with open-water areas every 5 years. Therefore, the predicted surface sediment concentrations account for the effect of vessel scour by assuming that subsurface sediment, surface sediment, and placed material (e.g., ENR material) are periodically mixed.
- Specification of aggregate mixes for ENR material can be designed and implemented to reduce impacts from the types of scour associated with vessel operations.
- Monitoring and adaptive management of these areas would trigger contingency actions if subsurface contamination is exposed.

- **Number of core stations outside of the dredge footprint:** The number of core stations with samples exceeding the CSL remaining following construction was used as a quantitative measure of contamination left behind. The action alternatives remove between 66 and 71 core stations (of a total of 76) that exceed the CSL. In addition, the majority of cores with CSL exceedances remaining after remediation are located under isolation caps for all alternatives. The alternatives leave up to 3 cores with CSL exceedances in ENR-sill and no action areas, with Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), and 2C+(12) leaving 3 cores behind, Alternatives 3B(12) and 3C+(12) leaving 2 behind, Alternative 2C+(7.5) leaving one core behind, and

Alternative 3E(7.5) leaving no cores behind. No cores exceed the CSL in MNR and in situ treatment areas for any of the alternatives.

- **The volume of contaminated sediment remaining after remediation** that could be disturbed by potential propwash erosion is reflected in the metrics above. In particular, the box model incorporates subsurface contaminant mixing (2 feet over much of the waterway), and therefore the predicted long-term risks include the contribution of any remaining contamination being transported by propwash into surface sediments. For the No Action Alternative, an estimated volume of 390,000 cy of contaminated sediment could be disturbed by propwash erosion.[150]

10.2.1.2 Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage residual risks from contaminated sediment that remains on site following remediation. As discussed in Section 10.2.1.1, the relative magnitude and importance of the post-remediation control components for the alternatives differ, primarily in relation to the potential for exposure of subsurface contaminated sediment under caps, and in MNR, partial removal and ENR-nav/ENR-nav, ENR-sill, and in situ treatment areas and the size of the disturbance event. The alternatives vary in amounts of monitoring, maintenance, and institutional controls used to manage residual risks and the potential for recontamination.

For this evaluation, adequacy and reliability of controls have five major aspects, as follows:

1. Controls of dredge residuals
2. Source control
3. Monitoring
4. Maintenance
5. Institutional controls

[150] Volume calculated by multiplying the area of sediment that exceeds RALs for the majority of the action alternatives (121 acres, which considers the upper 2 feet of sediment in potential propwash areas) by a potential mixing depth of 2 feet.

Control of Dredge Residuals

All dredging projects leave behind some level of residual contamination immediately after completion of in-water work (USACE 2008b). Dredge residuals are produced by the resettling of sediments suspended during dredging, subsequent disturbance, and transport of the material just outside the dredged area (coarser resuspended material) or well beyond the dredge operating area (fine-grained material) (USACE 2008b; Bridges et al. 2010; Patmont and Palermo 2007). Surface sediments in the EW will be affected to some degree by dredge residuals following remediation. The management of dredge residuals was acknowledged in the development of alternatives (Section 8) with a cost and modeling assumption that dredging would be followed by a thin-layer placement of RMC sand layer as an engineering control for dredge residuals. The dredge residuals management approach and decision framework will be developed during remedial design (Appendix B, Part 5).

Source Control

Potential sources to the EW are regulated under existing state and federal programs. EW source control evaluations and actions to date include source tracing and line cleaning.[151] In addition, programs such as spill response and business inspections are conducted in the EW drainage basins as part of compliance with NPDES permit requirements (e.g., for stormwater and CSO discharges) and MTCA (e.g., for upland cleanup sites adjacent to the EW). These programs enforce stringent federal and state standards (e.g., the CWA), and incorporate reporting and review cycles for transparency, corrective action, and adaptive management. A summary of each source control-related program and how it relates to the EW source control strategy is provided in Section 2.12.2. Under any of the FS alternatives, incoming solids from local lateral inputs are addressed under ongoing source control programs.

The box-model sensitivity evaluation in Appendix J indicates that lateral sources have a minor impact on site-wide SWACs compared to upstream sources, and therefore, are not a major driver for reducing site-wide risks. In addition, the recontamination evaluation presented in Section 9.14 predicts that the potential for recontamination above RALs in very localized areas near some outfalls and may occur in the EW for a few contaminants

[151] Source tracing and line cleaning in City storm drains has been performed voluntarily.

(dioxins/furans, BEHP, mercury, and 1,4-dichlorobenzene). A source control sufficiency evaluation will be completed prior to remedy construction.

As discussed in Appendix K, direct atmospheric deposition to the EW surface does not appear to be a major pathway for most contaminants to the EW, although it could be comparable to EW lateral inputs for some COCs, specifically for BEHP and dioxins/furans. Estimates of inputs from atmospheric deposition have not been incorporated into modeling for recontamination potential or future SWACs; therefore, there is some uncertainty associated with its overall impact. In addition, indirect atmospheric deposition to drainage basins could be a significant contribution the EW lateral loads.

Persistent legacy compounds such as total PCBs can be expected to diminish over time as a result of ongoing source control. Other contaminants (e.g., cPAHs, dioxins/furans, and phthalates) continue to be generated and released into the environment from a variety of non-point sources (e.g., vehicles, combustion of organics, and PVC). Technological advances or societal changes (e.g., energy use, transportation, infrastructure investment [particularly in source control], and waste generation, handling, and recycling) and many other possible factors will continue to affect ongoing inputs to the EW. Collectively, the pace and efficacy of these factors make predictions for the EW uncertain. However, ongoing sources will affect the adequacy and reliability of all alternatives equally, so, while important, source control does not factor into the comparative analysis of alternatives.

Monitoring

Monitoring is a key assessment technology for sediment remediation. Monitoring of surface and subsurface sediment, fish and shellfish tissue, porewater, and surface water quality will be required for any alternative selected for cleanup of the EW. Pre-construction baseline monitoring will be conducted to establish baseline conditions for comparison to post-construction performance monitoring results. During construction, location-specific construction monitoring data and confirmation sampling will be used to verify the performance of the operations and identify the need for construction contingencies, such as the placement of RMC following dredging. Operations and maintenance monitoring methods will be used to measure the post-construction and long-term performance of the remedial technologies (such as MNR). Finally, long-term EW-wide monitoring data will also

be used to assess the post-construction and long-term performance of remediation with respect to achievement of RAOs (that ensure protection of human health and the environment) and to identify sediment recontamination.
Differences among the alternatives in the adequacy and reliability of long-term post-cleanup monitoring are minor. The scope and duration of monitoring are similar for the action alternatives. However, alternatives with MNR, ENR, and in situ treatment components would require the collection of more project-specific operation and maintenance monitoring data to achieve data quality objectives, and have more potential for contingency actions in the future.

As previously stated, the entire EW will require monitoring under all alternatives, including the underpier area using any technology assignment. The difference among the alternatives is whether they have large, moderate, or small surface areas that require technology-specific performance monitoring (i.e., cap, ENR, in situ treatment, and MNR) during the monitoring period (Table 10-1). For the No Action Alternative, only site-wide monitoring was assumed. For the action alternatives, the monitoring scope is similar due to the similar scope of the alternatives (i.e., primary reliance on removal, with some reliance on partial removal and capping, ENR, in situ treatment, and MNR depending on the alternative) with differences due to the differences in acres of MNR, ENR, and in situ. Appendix G presents the assumed scope of monitoring for the alternatives.

Maintenance

After construction, long-term monitoring is useful in identifying and assessing remediated areas that may not perform as anticipated (e.g., cap instability). Therefore, maintenance may be required to address needed repairs and adaptive management responses (including contingency actions where appropriate), which would decrease the residual risk of post-remediation exposure to subsurface contaminated sediment.

Maintenance technologies are drawn from the same set of technologies used to develop the alternatives. The primary maintenance technologies are dredging or application of cover material (e.g., to repair a cap or ENR area).[152] These activities are performed using the same marine construction technologies employed during remedy construction. These technologies are as reliable for maintenance as they are for constructing the alternatives themselves, assuming that the engineering, planning, and execution of the repairs are done with a similar level of proficiency. As presented in Section 7.2.5.4, capping has been shown to be a successful, reliable, and proven technology, effective at many CERCLA sites within the Puget Sound where caps have been in place for more than 15 years and are performing as designed.

Alternatives with more removal have a reduced level of effort for maintenance compared to alternatives with more containment, ENR, and MNR. ENR, in situ treatment, and MNR areas are assumed to have a higher maintenance requirement (i.e., per unit area) compared to capping. The contribution of the maintenance evaluation factor to the ranking of the long-term effectiveness and permanence balancing criteria is qualitatively assessed by whether the alternatives have large, moderate, or small surface areas to maintain and whether a moderate or higher level of effort for monitoring or maintenance is expected (Table 10-1). Therefore, the comparison of alternatives with regard to maintenance requirements is the same as previously discussed for monitoring.

Institutional Controls

Institutional controls are needed for all alternatives because thresholds of excess cancer risk of 1×10^{-6} and non-cancer HQs less than 1 are associated with levels in sediment below natural background for total PCBs, dioxins/furans, and arsenic. In addition, none of the alternatives achieve natural background-based PRGs for total PCBs or dioxins/furans for RAO 1. Thus, remaining risks to the community from consuming resident fish and shellfish would be managed by institutional controls designed to reduce such seafood consumption exposures. While the No Action Alternative includes no provisions for site-wide institutional controls to manage residual risks, the action alternatives would require an ICIAP for the EW. The ICIAP would include several elements, such as a notification, monitoring, and reporting

[152] In developing the alternatives, a specific assumption was made that 15% of designated MNR, ENR, and in situ treatment areas of any given alternative will require additional remediation as a contingency action based on remedial design sampling or subsequent monitoring data.

program for areas of the EW and WDOH seafood consumption advisories, public outreach, and education programs.

Monitoring and notification of waterway users is essential where contamination remains in place above levels to ensure the performance of the remedy (particularly the containment-focused alternatives, in areas where capping has been utilized). The essential components of these programs, as discussed in Section 7.2.2.2, could include elements such as the following proprietary controls:

- Reviewing USACE dredging plans and other Joint Aquatic Resource Permit Application construction permitting activities to identify any projects with the potential to compromise containment remedies or potentially disturb contamination remaining after remediation. EPA would be notified during the permitting phase of any project that could affect containment remedies.[153]
- Using signs, RNAs, and other forms of public notice to inform waterway users about restrictions in areas where contamination remains in place.

The second element of the ICIAP includes seafood consumption advisories and public education and outreach programs. Dependence on these programs to reduce exposures may be more critical in the short term during construction periods because fish and shellfish tissue concentrations are predicted to remain elevated throughout the construction period and for some time thereafter, resulting in a period of continued elevated resident seafood consumption risks. As discussed in Section 7.2.2.2, WDOH issues seafood consumption advisories, although it is not necessarily the exclusive issuing authority.[154] Advisories are informational devices that are not enforceable against potential consumers of EW fish and shellfish, and they can have poor compliance. Thus, enhanced public education and outreach efforts are crucial to reduce exposures through changes in behavior (e.g., encouraging consumption of migratory fish, such as salmon, which are safer to eat than resident seafood in the EW). The education programs could be developed and administered by responsible

[153] This function is currently in place in the form of a Standard Operating Procedure agreed upon between EPA and USACE, and the existing mechanism could either be funded or assumed by the responsible parties.
[154] EPA may also select, design, and require implementation of seafood consumption advisories like any other institutional control to help reduce exposures to hazardous substances.

parties with EPA oversight and participation from local governments, tribes, and other community stakeholders.

10.2.1.3 Summary of Long-term Effectiveness and Permanence

For long-term effectiveness and permanence, the alternatives are ranked relative to other alternatives, with five stars representing the most effective in the long term and most permanent, and one star representing the least effective in the long term and least permanent. The ranking considers both factors described above, equally: 1) risk reduction achieved by the alternative in the long term and magnitude and type of residual risk remaining; and 2) adequacy and reliability of engineering controls, considering the area of the waterway with contamination permanently removed, and the area with remaining contamination that will require technology-specific monitoring and maintenance, beyond site-wide monitoring.

As shown in Table 10-1, the No Action Alternative has the lowest relative rank (★) for long-term effectiveness and permanence because it would not achieve all of the RAOs, it would leave the largest amount of subsurface contamination in place, and it would not provide reliable controls. All of the action alternatives are considered highly permanent due to a primary reliance on removal (between 80% and 99% of the remediation area undergoes removal or partial removal). Alternative 1A(12) ranks moderately (★★★) because it removes the least amount of contaminated sediment among the action alternatives, has slightly higher residual risks in the long term (due to reliance on MNR), and would leave an area managed without engineering controls (i.e., MNR). Alternatives 1B(12) and 1C+(12) rank higher (★★★★) because they achieve slightly lower risks than Alternative 1A(12), but would remove a similar amount of contaminated sediment as Alternative 1A(12) and have a larger area managed by ENR and in situ treatment. Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) score highest (★★★★★) because they achieve similar risks as among the action alternatives, and they rely more on removal than Alternatives 1B(12) and 1C+(12), and are therefore likely to be more permanent. All alternatives include little ENR and limited engineered (armored) capping, which is considered highly permanent for this evaluation.

10.2.2 Reduction in Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to permanently and significantly reduce the toxicity, mobility, or volume of site contaminants. Based on EPA guidance, the contaminated sediments within the EW are classified as low-level threat wastes because they are not highly toxic or highly mobile such that they generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur (Section 9.1.2.2).

All action alternatives, except for Alternative 1A(12), include in situ treatment using activated carbon or other sequestering agents as a remedial technology. Activated carbon lowers the mobility of contaminants, reducing the toxicity and bioavailability to biological receptors directly in areas where it is applied and indirectly site-wide through reduced releases to the water column, which lowers average exposure to receptors. The amendment material is often placed as part of a clay, sand, or gravel matrix to deliver the amendment to the sediments in a reasonably stable lift.

For FS comparison purposes, the reduction of mobility achieved by in situ treatment is assumed to be proportional to the area that undergoes treatment. The alternatives are ranked relative to each other, with those alternatives using the most use of in situ treatment relative to the other alternatives (e.g., > 10 acres) receiving five stars, and alternatives with no in situ treatment receiving one star. Alternatives 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) employ in situ treatment in underpier areas above RALs (varying from 12 to 13 acres) and therefore rank the highest (★★★★★) for this balancing criterion. The No Action Alternative and Alternative 1A(12) have low ranks (★) because they do not treat any contaminated sediment.

10.2.3 Short-term Effectiveness

This evaluation criterion addresses the effects of the alternatives on human health and the environment during the construction phase of the remedial action and until RAOs are achieved. This criterion includes the protection of workers and the community during construction, environmental impacts that result from construction, and the length of time until RAOs are achieved (Section 9.1.2.3).

10.2.3.1 Community and Worker Protection

This aspect of short-term effectiveness addresses impacts to human health from construction of the alternatives. Short-term impacts to both workers and the community are largely proportional to the length of the construction period (Table 10-1);[155] thus, longer construction periods are associated with greater relative impacts. In general, disruptions and inconveniences to the public and commercial community (e.g., increased street and vessel traffic, and potential temporary waterway restrictions) can be expected to increase with the duration of construction. Also, consumption of resident seafood that occurs during construction, despite the current WDOH advisory against consuming any such seafood, presents short-term risks to the community because concentrations of COCs in resident seafood are expected to remain elevated during and for some time after the period of construction as a result of contaminated sediment resuspension and biological uptake.

Local transportation impacts (e.g., traffic, noise, and air pollutant emissions) resulting from the implementation of the alternatives may affect the community. In this FS, these impacts are assumed to be proportional to the number of truck, train, and barge miles estimated for support of material hauling operations, both for the disposal of contaminated sediment and for the transportation of sand, gravel, armor stone, and activated carbon used in capping, ENR, backfilling of dredged areas, RMC, and in situ treatment. Table 10-1 summarizes estimates of truck, train, and barge miles under each alternative. Transportation-related impacts would be managed in part with traffic control plans developed during remedial design in consultation with affected stakeholders. All of the action alternatives have large impacts from truck, train, and barge miles due to the larger amounts (810,000 to 1,080,000 cy) of sediments being removed from the EW. Alternatives 1A(12), 1B(12), and 1C+(12) have the lowest transportation impacts from truck, train, and barge miles to remove 810,000 to 820,000 cy of sediment. Alternatives 2B(12), 2C+(12), 3B(12), and 3C+(12) have moderate transportation impacts due to removing 900,000 to 960,000 cy of sediment, and

[155] As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15), the upper end of the number of work days in a construction season could increase to around 150 days/season, which could reduce the total number of years of construction by about 2 years, consistently across the action alternatives.

Alternatives 2C+(7.5) and 3E(7.5) have the largest transportation impacts due to removing 1,010,000 to 1,080,000 cy of sediment.

Activities on the construction site related to the operation of heavy equipment pose the greatest risk of physical accidents (injuries or fatalities). Risk to workers from exposure to site-related contaminants is generally low and is managed through established health and safety requirements for hazardous materials site work. Nevertheless, in both cases, the potential for exposure, injury, or fatality increases in proportion to the duration of construction activities, volume of material handled, and transportation requirements. Diver-assisted hydraulic dredging inherently has more risk for workers than any of the other construction activities, with risks for injury and death increasing with greater duration and amount of this activity. Safety concerns associated with diver-assisted hydraulic dredging used to address underpier areas for Alternatives 1C+(12), 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5) are proportional to the duration of this activity. Alternative 3E(7.5) poses the highest risk to worker safety because of the amount of hazardous diver-assisted hydraulic dredging included (12 construction years compared to 0 or 2 for other alternatives). Vessel navigation and berthing will also be restricted where construction activities are being conducted (e.g., sediment removal, material placement, and diving) to minimize the potential for accidents.

10.2.3.2 Environmental Impacts

Cleaning up the EW will have short-term environmental impacts that can be grouped into the categories of air pollutant emissions, landfill capacity utilization, depletion of natural resources, ecological impacts, and energy consumption. In general, longer duration alternatives and those with more removal have greater short-term impacts in all of these categories than similarly scaled alternatives that use more containment or ENR and MNR (see Table 10-1).

All alternatives except the No Action Alternative have similarly large remediation footprints, so the areal extent of short-term disturbances to the existing benthic community and other resident aquatic life is comparable. Due to dredging and capping activities during the construction phase, concentrations of bioaccumulative contaminants (e.g., total PCBs) are likely to remain elevated in the tissues of aquatic organisms, such as fish. Finally, damage or destruction of the benthic community would reduce food sources for other organisms until the biologically active zone is recolonized and the ecological functions are re-established.

Although BMPs (e.g., controls on dredge operations) will be used to minimize resuspension of contaminated sediment during dredging, some releases are an inevitable short-term impact. Resuspended material would resettle primarily on the dredged surface and in other areas outside of the dredge footprint. Dredging also releases contaminants into the water column. The impacts from resuspension increase relative to the amount of material dredged in each alternative. Adequate controls to manage dredge residuals that are deposited in the near-field (i.e., thin-layer sand placement as RMC) can be included in engineering design requirements and are an assumed element of the alternatives developed in this FS. Alternatives with more removal require more dredge residuals management actions than alternatives with more containment, ENR, and MNR.

Longer construction timeframes increase air pollutant emissions from construction equipment and noise. Air pollutant emissions include components with local environmental impacts (e.g., sulfur oxides or nitrogen oxides), those that can cause respiratory problems (e.g., PM_{10} and $PM_{2.5}$), and those with global impacts (e.g., carbon dioxide and other greenhouse gases). The primary source of air pollutant emissions is fuel consumption during construction activities. Transloading, transportation, and disposal of contaminated sediments account for the largest portion of the emissions, followed by emissions from material placement and dredging. The FS assumes that rail and barge transport will be used to the maximum extent possible. This is the most efficient way to reduce air pollutant emissions and will significantly reduce project air pollutant emissions as compared to long-haul trucking. Additional incremental reductions in air pollutant emissions may be possible by using BMPs during construction. Examples of BMPs that can be used to reduce emissions (e.g., use of biodiesel fuels) are discussed in Appendix I.

The alternatives consume quarry materials (e.g., sand, gravel, or armor stone) to satisfy the varying requirements for capping, backfilling (for habitat restoration), ENR, and RMC (Table 10-1). All alternatives have a similar total material placement volume (270,000 to 290,000 cy), although they vary in the use of that material (e.g., as capping material is reduced, RMC material increases).

All of the action alternatives greatly rely on dredging, and therefore consume landfill space proportional to the total removal volume (Table 10-1). Alternatives that include partial removal and ENR-nav/ENR-nav (i.e., Alternatives 1A(12), 1B(12), and 1C+(12)) consume less landfill space (810,000 to 820,000 cy removed from the waterway) than the other action alternatives (i.e., Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5) and 3E(7.5); 900,000 to 1,080,000 cy removed from the waterway).

Energy required during the construction of the alternatives includes not only the energy consumed to remove sediment and dispose of it at a landfill, but also to transport and place all capping and in situ treatment materials at the EW. Alternative 3E(7.5) has the largest energy consumption because of its large removal volume, while Alternative 1A(12) has the lowest energy consumption because of its higher use of ENR and MNR. The other action alternatives have moderate energy consumption.

The carbon footprint is defined as the forested area necessary to absorb the carbon dioxide produced during the remedial activities for each alternative. This metric is dependent on the carbon dioxide emissions associated with generation of the energy needed to implement any alternative, and therefore the carbon footprint is proportional to energy consumption discussed in the preceding paragraph.

10.2.3.3 Time to Achieve RAOs

Table 10-1 presents the predicted times at which the alternatives achieve RAOs (based on start of construction as year 0 and taking into account the construction periods; see Section 9.1.2.3), as follows:

- **RAO 1:** All action alternatives are predicted to achieve the same order of magnitude cancer risk and non-cancer HQ. Alternative 1A(12) is predicted to achieve 1×10^{-5} order of magnitude cancer risk for Child Tribal RME in a longer timeframe than the other action alternatives (34 years from the start of construction), while the other action alternatives achieve it at the end of construction (9 to13 years, depending on the alternative). All of the action alternatives are predicted to achieve the other risk metrics at the end of construction (9 to13 years, depending on the alternative).

- **RAO 2:** All action alternatives are predicted to achieve the arsenic PRG both site-wide and in clamming areas at the end of construction. Model predictions indicate that arsenic concentrations in the EW could increase following construction, and maintaining the PRG in the long term is uncertain because of incoming sediment concentrations.
- **RAO 3:** Alternative 1A(12) is predicted to achieve the RAO 3 PRGs 39 years from the start of construction), while the other action alternatives are predicted to achieve it immediately after construction completion (9 to 13 years, depending on the alternative). The No Action Alternative is not expected to achieve the RAO 3 PRGs.
- **RAO 4:** The No Action Alternative is predicted to achieve RAO 4 PRGs at 10 and 25 years for English sole and brown rockfish, respectively, while all action alternatives are predicted to achieve RAO 4 PRGs after construction completion (9 to 13 years, depending on the alternative).

Overall, Alternatives 1B(12) and 1C+(12) are predicted to achieve RAOs 2 through 4 in 9 years, followed by Alternatives 2B(12), 2C+(12), 3B(12), and 3C+(12) in 10 years; 2C+(7.5) in 11 years; 3E(7.5) in 13 years; and 1A(12) in 9 years for RAOs 2 and 4 and 39 years for RAO 3. All action alternatives are predicted to meet similar risk thresholds for RAO 1 within 9 to 13 years except Alternative 1A(12), which is predicted to take 34 years to achieve similar child tribal risk thresholds.

As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years, consistently for all action alternatives, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented in Section 9 and Table 10-1.

10.2.3.4 Summary of Short-term Effectiveness

For short-term effectiveness, the alternatives are ranked relative to each other, with five stars representing the most effective in the short-term, and one star representing the least effective in the short-term. The ranking balances the considerations discussed above, with the following three summary metrics considered equally: 1) community and worker protection during construction, which includes the duration of hazardous work (diver-assisted dredging); 2) environmental impacts from construction, including as a result of dredge releases, transportation, consumed landfill capacity, air emissions, energy consumption, and carbon footprint during implementation; and 3) the time to achieve RAOs (as a measure of the residual risk that is present on site until the RAOs are met).[156]

As shown in Table 10-1, the No Action Alternative has a low rank (★) because, although it has no impacts associated with construction (as no actions are included in its scope), it is not expected to achieve most of the RAOs. Alternative 3E(7.5) also ranks low (★) because it would: 1) have the greatest community and worker impact as it takes the longest to construct, and would have the highest potential for work-related accidents (due to 12 construction years of diver-assisted hydraulic dredging in underpier areas); 2) have the greatest environmental impacts as it consumes the greatest amount of energy and landfill space, generates the most transportation-related impacts, produces the most air pollutant emissions, has the largest carbon footprint, creates the longest periods of elevated bioaccumulation and exposure in resident species, and disturbs the largest surface area of benthic community and higher value habitat (i.e., shallower than -10 feet MLLW); and 3) has the longest time to achieve RAOs of the active alternatives. Alternative 1A(12) ranks relatively low (★★) because, although it has the lowest construction-related impacts of the action alternatives, it takes longer to achieve RAO 3 and 1 x 10^{-5} order of magnitude risk for Child Tribal RME, compared to the other action alternatives, due to some reliance on MNR. Alternative 2C+(7.5) also ranks low (★★) because of moderately more construction impacts compared to the action alternatives (11 years of construction; 2 years of diver-assisted hydraulic dredging) and moderately longer time to achieve RAOs (11 years). Alternatives 2C+(12) and 3C+(12) have a moderate ranking (★★★) due to the moderate construction impacts (10 years of construction, including 2 years of diver-assisted hydraulic dredging, and removal of 910,000 to 960,000 cy of sediment), and moderate time to achieve RAOs (following 10 years of construction). Alternatives 1C+(12), 2B(12), and 3B(12) are ranked relatively higher (★★★★) due to lower impacts to human health and the environment from construction activities, and having a moderately shorter time to achieve

[156] Times to achieve RAOs could be reduced if a longer construction window is allowed, as the total number of years of construction could decrease by about 2 years, consistently for all action alternatives (see Section 9.1.2.3). However, the total number of construction days and associated construction impacts would remain unchanged.

RAOs (immediately post-construction). Alternative 1C+(12) requires 9 years of construction, 2 years of diver-assisted hydraulic dredging, and 820,000 cy of removal, and Alternatives 2B(12) and 3B(12) require more overall construction (10 years of construction and 900,000 or 960,000 cy of removal), but no diver-assisted hydraulic dredging. Alternative 1B(12) ranks highest (★★★★★) by having the least construction impacts among the alternatives (9 years of construction, no diver-assisted hydraulic dredging, 810,000 cy of removal), and achieving RAOs immediately following construction.

10.2.4 Implementability

Technical implementability, administrative implementability, and availability of services and materials are factors considered under this criterion (Section 9.1.2.4). Technical feasibility encompasses the complexity and uncertainties associated with implementation of the alternative, the reliability of the technologies, the ease of undertaking potential contingency remedial actions, and monitoring requirements. Administrative feasibility includes the activities required for coordination with other parties and agencies (e.g., consultation, obtaining permits for any off-site activities, or rights-of-way for construction). Availability of services and materials includes the availability of necessary equipment, materials, and specialists and the ability to obtain competitive bids for construction.

This implementability evaluation primarily focuses on the first two factors because the alternatives use the same types of technologies or the same types of equipment and methods, all of which are available and for which expertise exists in the Puget Sound region. The following sections discuss technical and administrative implementability during and following the construction phase of the project (i.e., in the long term), as summarized in Table 10-1. The No Action Alternative has no implementability challenges, while the action alternatives all represent large, complex remediation projects with many technical and administrative challenges.

10.2.4.1 Technical Implementability

The technical implementability challenges are similar across the action alternatives in open-water areas, but are different across these alternatives in underpier areas. The technical challenges associated with open-water dredging include the stability of structures adjacent to removal operations, managing controls during dredging (e.g., water quality criteria), and efficiently dewatering and transloading sediments. Technical challenges associated with capping include evaluating slope stability, constructing for scour mitigation, and cap placement and maintenance. Technical challenges for ENR are fewer than for dredging or capping and include predicting remedial performance when specifying material mixtures and thicknesses and accounting for physical and chemical interactions with existing sediments. Evaluating source control is a common technical challenge to all action alternatives.

The action alternatives vary widely in the degree of technical challenges for remediating underpier areas; few technical challenges for MNR (related to monitoring and potential contingency actions), moderate technical challenges for in situ treatment material placement, and the most technical challenges for diver-assisted hydraulic dredging. MNR, as part of Alternative 1A(12), has few technical challenges, with the lowest potential for difficulties and delays and impacts to EW tenants and users.

In situ treatment and diver-assisted hydraulic dredging in underpier areas have larger technical challenges than MNR. Alternatives 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) have either in situ treatment or both in situ treatment and diver-assisted hydraulic dredging in underpier areas.

For in situ treatment, selection of the treatment material depends on many site-specific chemical and physical factors that will require close consideration. Placement of in situ treatment material would be performed by conveyors, which is more complex than placement in open-water areas (see Section 8.1.2.1).

As discussed in Section 9.1.2.4, diver-assisted hydraulic dredging has the most technical challenges of any technology in underpier areas. This form of dredging is more difficult to implement than the other technologies, particularly in underpier areas of EW, where divers will be operating the dredge on steep slopes (1.75H:1V in most areas) composed of large riprap. Work will be conducted in deep water, which limits dive time for each diver and may require use of decompression chambers (as required by commercial diving regulations), resulting in a large team of divers to complete the work over a period of months and years. Technical challenges are also associated with low visibility as a result of shade from the pier, deeper water, and sediments suspended as part of the work, making the work more hazardous from a worker health and safety perspective. Debris, such as cables, large wood, and broken pilings, will also make dredging more difficult and potentially more risky. Technical challenges are also present with respect to infrastructure, such as existing piling and cross bracing, which will require relocation of both floating and submerged lines in and out of each bent.

Hydraulic dredging generates large quantities of slurry (sediment/water) that must be treated prior to discharge back to the waterway. Upland areas are not available for slurry storage, sediment settling, effluent treatment, testing, and discharge because of Port operations at existing terminals. Pipeline transport of the slurry to a single upland staging location is also not feasible because of impacts to navigation and long pipeline transport distances in the waterway. Therefore, it is most likely that the sediment slurry will need to be handled using a portable treatment system on a barge, which limits the daily production rate and complicates the staging, water containment, dewatering, and treatment.

Underpier areas are adjacent to active berthing areas. Use of berthing areas averages around 300 large container ships per year and 600 total vessel calls per year in the EW.[157] Placement of in situ treatment materials and diving schedules are likely to be significantly impacted by waterway activities, which could result in delays in completing the work. In particular, dive time may be further limited due to risks posed to divers from propwash and suction forces from transiting and berthing container vessels. Similarly, more business interruption will occur as a result of hydraulic dredging because of restricted access to areas where divers are performing underwater work. Alternatives 2C+(12), 3C+(12), and 2C+(7.5) employ diver-assisted hydraulic dredging followed by placement of in situ treatment material over limited areas, and Alternative 3E(7.5) employs diver-assisted hydraulic dredging over the entire underpier area exceeding RALs followed by placement of in situ treatment material.

[157] Total vessels include tugs, fuel barges, and other barges that are docking at Port facilities. The number does not include additional vessels that are not part of Port records (e.g., Olympic Tug and Barge activities).

10.2.4.2 Administrative Implementability

After construction, the alternatives vary in the potential for contingency actions related to maintaining the remedy in ENR, in situ treatment, and MNR areas. Although all of the alternatives rely primarily on dredging, Alternatives 1A(12), 1B(12), and 1C+(12) have more areas with potential future contingency actions (29 to 31 acres), Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), and 2C+(7.5) have some areas with potential future contingency actions, (11 to 15 acres), and Alternative 3E(7.5) has 1 acre of area with potential future contingency actions.

An administrative feasibility factor for the EW is that in-water construction is not allowed year-round in order to protect juvenile salmon and bull trout migrating through the EW. The in-water work window is estimated to be October 1 to February 15, a period that will be confirmed by EPA in consultation with the National Marine Fisheries Service and U.S. Fish and Wildlife Service before implementation. In addition, coordination is necessary with the tribes, Port tenants, and other waterway users to ensure that impacts to their activities are minimized during remediation because the EW is a busy working industrial waterway and used by tribes for a commercial salmon netfishery (see Section 8.1.1.8). This feasibility factor affects all the action alternatives similarly, generally proportional to the construction timeframe for the alternatives.

The action alternatives vary with respect to the need to reauthorize the federal navigation channel. Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), and 2B(7.5) include partial dredging and capping in the Shallow Main Body – South CMA, where the cap would be placed at elevations shallower than the current authorized elevation. Reauthorization from -34 to -30 feet MLLW is assumed for this FS to make some remedial actions feasible and appears to be a reasonable assumption based on current and anticipated future site use, but actual depths would need to be approved by USACE in coordination with waterway users as part of the reauthorization process. Another administrative challenge common to all action alternatives is associated with partial dredging and capping on state-owned aquatic land, which may be subject to DNR approval and a site use authorization.

10.2.4.3 Summary of Implementability

For implementability, the alternatives are ranked relative to each other, with five stars representing the most implementable, and one star representing the least implementable. The ranking considers two primary metrics equally: 1) technical implementability, with the key differentiating factor being the approach to remediating the technically challenging sediments under the piers; and 2) administrative implementability, with the key differentiating factor being the overall complexity of the cleanup which accounts for annual challenges of permitting, fisheries coordination, Port tenant and shipping vessel coordination, and staging. Contingency actions are also included in the ranking for implementability; however, this is considered a secondary metric that is weighted less in the overall ranking because contingency actions are potential conditions only.

The overall implementability rankings take into account all of the implementability considerations, but focus primarily on the key distinguishing components of the alternatives: the underpier technology employed and the overall scope of cleanup. Alternative 3E(7.5) receives the lowest rank (★) for implementability relative to the other alternatives, largely due to technical challenges associated with 12 construction years of diver-assisted hydraulic dredging over large areas of underpier sediment, placement of in situ treatment material under the piers, and the largest overall scope of the alternatives (13 years of construction). Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5) receive a relatively low ranking (★★) because they employ some diver-assisted hydraulic dredging followed by in situ treatment under the piers and have moderate overall scope of remediation (9 to 11 years). Alternatives 1B(12), 2B(12), and 3B(12) are considered moderately implementable (★★★) because they use in situ treatment in underpier areas and have moderate overall scope of remediation (9 to 11 years). Alternative 1A(12) scores highest among the action alternatives because of the high implementability of performing MNR under the piers (★★★★), and a moderately lower overall scope (9 years of construction). The No Action Alternative is given the highest implementability rank (★★★★★) because it has no construction elements and no provisions to trigger contingency actions.

10.2.5 Costs

This assessment evaluates the construction and non-construction costs of each alternative (Section 9.1.2.5). Detailed cost estimates for each alternative are presented in Appendix E and include assumptions for monitoring, project management, design, agency review and oversight, and contingency actions. Costs for contingency are included as a percentage of the construction costs (30%) to cover unknowns, unforeseen circumstances, and unanticipated conditions reducing the overall risk of cost overruns. Of this percentage, costs for potential contingency remedial actions are assumed to be needed in 15% of MNR, ENR, and in situ treatment areas. The estimates do not include anticipated costs for upland remediation or source control efforts. Total project costs for the alternatives are expressed in NPV and 2016 dollars and are assumed to be accurate within the range of -30% to +50%.

As discussed in Appendix E, the costs are very sensitive to the estimated dredge removal volume. Modest changes in dredge design factors (e.g., dredge footprint, depth of contamination, depth required for navigation clearance, side slope designs, or the amount of diver-assisted hydraulic dredging) can result in significant changes to dredge volumes and costs. Other factors, such as fuel and labor, can also significantly impact costs. The costs provided represent the best estimate of total costs for the proposed EW alternatives; however, several uncertainty factors discussed in Appendix E may affect the cost estimate and the actual cleanup costs.

The No Action Alternative is ranked five stars as the least expensive. The action alternatives are ranked relative to each other, with four stars representing the least expensive and one star representing the most expensive. The action alternatives are grouped based on ranges of costs using intervals of $30 million (i.e., $240 to $270 million, $270 to $300 million, and $300 to $330 million). Alternative 3E(7.5) has the highest cost ($411 million), and therefore ranks lowest (★) for this criterion. Alternatives 3C+(12) and 2C+(7.5) are assigned the next lowest rank (★★), with costs of $310 and $326 million, respectively. Alternatives 1C+(12), 2B(12), 2C+(12), and 3B(12) receive a moderate ranking (★★★) with costs from approximately $277 to $298 million. Alternatives 1A(12) and 1B(12) receive a high ranking (★★★★) with costs from approximately $256 and $264 million. The No Action Alternative has lowest cost, at $950,000, and has the highest ranking for cost (★★★★★).

10.3 Modifying Criteria – State, Tribal, and Community Acceptance

The community acceptance criterion refers to acceptance of EPA's preferred alternative in the ROD following the public comment period on EPA's Proposed Plan (Section 9.1.3). Therefore, Table 10-1 does not include alternative ranks for the state, tribal, and community acceptance criterion.

11 CONCLUSIONS

Cleanup of the EW is a complex, large-scale undertaking that seeks to accomplish important protections of human health and the environment in a challenging urban/industrial setting. This FS evaluated multiple factors to develop and compare a range of remedial alternatives for the EW that are protective over the long term. These factors include the following:

- Nature and extent of contamination, associated human health and environmental risks, and development of relevant RAOs and PRGs
- Applicability and limitations of the remedial technologies for areas within the EW OU
- Estimated short-term and long-term effectiveness of remedial alternatives, considering the effectiveness of remedial technologies and the physical/chemical factors, such as contaminant concentrations of incoming sediment and potential vessel scour

The National Research Council (NRC) published a report in 2007 on sediment cleanups at large Superfund sites that identifies similar challenges at sites elsewhere in the country and suggests how to move forward in selecting remedies for sites as large and complex as the EW. The report concludes with the following excerpt:

> *If there is one fact on which all would agree, it is that the selection and implementation of remedies at contaminated sediment sites are complicated. Many large and complex contaminated sediment sites will take years or even decades to remediate and the technical challenges and uncertainties of remediating aquatic environments are a major obstacle to cost-effective cleanup.*
>
> *Because of site-specific conditions—including hydrodynamic setting, bathymetry, bottom structure, distribution of contaminant concentrations and types, geographic scale, and remediation time frames—the remediation of contaminated sediment is neither simple nor quick, and the notion of a straightforward "remedial pipeline" that is typically used to describe the decision-making process for Superfund sites is likely to be at best not useful and at worst counterproductive.*

> *The typical Superfund remedy-selection approach, in which site studies in the remedial investigation and feasibility study establish a single path to remediation in the record of decision, is not the best approach to remedy selection and implementation at these sites owing to the inherent uncertainties in remedy effectiveness. At the largest sites, the time frames and scales are in many ways unprecedented. Given that remedies are estimated to take years or decades to implement and even longer to achieve cleanup goals, there is the potential—indeed almost a certainty—that there will be a need for changes, whether in response to new knowledge about site conditions, to changes in site conditions from extreme storms or flooding, or to advances in technology (such as improved dredge or cap design or in situ treatments). Regulators and others will need to adapt continually to evolving conditions and environmental responses that cannot be foreseen.*
>
> *These possibilities reiterate the importance of phased, adaptive approaches for sediment management at megasites. As described previously, adaptive management does not postpone action, but rather supports action in the face of limited scientific knowledge and the complexities and unpredictable behavior of large ecosystems.* (NRC 2007)

In that context, Section 11.1 discusses key conclusions related to protecting human health and the environment by comparing the remedial alternatives with respect to their compliance with CERCLA criteria. Risk management principles and national guidance are discussed in Section 11.2. Section 11.3 briefly describes the uncertainties associated with the alternatives and their predicted outcomes. Finally, Section 11.4 discusses the next steps in the process for selecting the remedy for the EW.

11.1 Summary of the Comparative Analysis

The remedial alternatives were evaluated using seven of the nine CERCLA criteria, which include two threshold criteria and five balancing criteria. The two threshold criteria, which must be met before the others can be considered, are:

- Overall protection of human health and the environment
- Compliance with ARARs of federal and state environmental laws and regulations

The five balancing criteria are:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

The two modifying criteria, state/tribal and community acceptance, were not evaluated at this time. EPA will evaluate state, tribal, and community acceptance of the selected remedial action in the ROD following the public comment period on EPA's Proposed Plan.

Figure 11-1 presents a summary of the comparative analysis under the CERCLA evaluation criteria. The No Action Alternative failed to meet CERCLA threshold criteria, but was retained as a basis to compare the relative effectiveness of the other alternatives. A high ranking (dark green dot) means that the alternative ranks high compared to other alternatives, whereas a low ranking (red dot) means the alternative ranks low compared to other alternatives. In some cases, the evaluation did not identify substantial differences among the alternatives and, therefore, the rankings are the same for those criteria.

Table 11-1 summarizes key factors considered in the comparison of the alternatives. The following sections discuss these key factors, organized by the two threshold and five balancing criteria under CERCLA.

11.1.1 Overall Protection of Human Health and the Environment

Assessment of overall protection of human health and the environment primarily draws on evaluation of long-term effectiveness and short-term effectiveness. All of the action alternatives (Alternatives 1A(12) through 3E(7.5)) meet the threshold requirement of overall protection of human health and the environment by reducing risks to human health and environment for each of the RAOs during and following construction.

Table 11-1
Summary of Comparative Evaluation of Alternatives

Evaluation Criteria			Alternative									
			No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Threshold Criteria												
Overall Protection of Human Health and the Environment												
Magnitude and Type of Residual Risk	RAO 1 – Human Health (Seafood Consumption) [a]	Total PCBs and Dioxins/Furans	Does not achieve.	The action alternatives are predicted to achieve total excess cancer risks of 2 to 3 × 10^{-4} (Adult Tribal RME), 4 to 5 × 10^{-5} (Child Tribal RME), and 1 x 10^{-4} to 9 × 10^{-5} (Adult API RME). The alternatives are also predicted to achieve total PCBs non-cancer risks (based on immunological, integumentary, or neurological endpoints only, which are the highest of the non-cancer risks) of HQ = 4 to 5 (Adult Tribal RME), HQ = 9 to 12 (Child Tribal RME), and HQ = 4 to 5 (Adult API RME).									
	RAO 2 – Human Health (Direct Contact)	Arsenic	All alternatives are predicted to achieve a total excess cancer risk less than 1 × 10^{-5}. For arsenic, all action alternatives achieve individual excess cancer risk of 2 x 10^{-6} for netfishing and 7 x 10^{-6} for clamming. Because the target risk threshold for arsenic is below natural background, the PRG is also used as a comparison; all action alternatives are predicted to meet the natural background-based PRG following construction, but increase above the PRGs in the long term, due to incoming Green River concentrations. The No Action Alternative is not predicted to meet the arsenic PRG.										
	RAO 3 – Ecological Health (Benthic Organisms)	29 COCs[b]	Not expected to achieve.	Alternative 1A(12) is predicted to meet benthic PRGs in 99% of point locations 40 years following construction.	Alternatives 1B(12) through 3E(7.5) are predicted to meet benthic PRGs in 100% of point locations after construction completion.								
	RAO 4 – Ecological Health (Fish)	Total PCBs	HQ > 1.0 using the lower LOAEL TRV; HQ ≤ 1.0 using the higher LOAEL TRV.	All action alternatives are predicted to achieve HQ ≤ 1.0 for English sole and HQs ≤ 1.0 for brown rockfish for the higher LOAEL TRV and 1.1 to 1.3 for the lower LOAEL TRV (assumptions regarding water concentrations result in HQs slightly above 1.0) at year 40 following construction.									
Compliance with ARARs													
MTCA/SMS			Not expected to comply for RAOs 1 and 3.	All action alternatives are predicted to achieve PRGs or risk targets for RAOs 2 through 4. For RAO 1, the action alternatives are not likely to meet all natural background-based PRGs. If EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs, EPA may adjust the cleanup level upward to the CSL, which could be attained in a reasonable restoration timeframe, consistent with the substantive requirements of SMS (see Sections 4.3.1 and 9.1.1.2), or waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).									
Surface Water Quality Standards			No active remedial measures are technically feasible or anticipated expressly for the water column, although water quality improvements are anticipated from sediment remediation and additional source control measures. It is not anticipated that any alternative can 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 (e.g., total PCBs and arsenic). If long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA will determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of technical impracticability in a future decision document (ROD Amendment or ESD).										
Achieve Threshold Criteria?			**No**	**Yes; however, one or more ARAR waivers may be required.**									
Balancing Criteria													
Long-term Effectiveness and Permanence													
Long-term Risk Outcomes			Does not achieve all.	See the risk outcomes for Magnitude and Type of Residual Risk above. The action alternatives achieve similar risk outcomes with Alternative 1A(12) having slightly higher risks.									
Technology Areas (acres; of 157 acres in the EW)	Most permanent: Removal		No controls assumed.	77	77	79	94	94	100	100	104	111
	Highly permanent: partial dredging and capping			13	13	13	13	13	7	7	13	7
	Moderately permanent: in situ treatment			0	12	12	12	12	12	12	13	13
	Less permanent: ENR-nav, ENR-sill, MNR			31	19	19	3	3	1	1	3	1
Ranking[c] for long-term effectiveness and permanence			★	★★★	★★★★	★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★

Table 11-1
Summary of Comparative Evaluation of Alternatives

Evaluation Criteria		Alternative									
		No Action	1A(12)	1B(12)	1C+(12)	2B(12)	2C+(12)	3B(12)	3C+(12)	2C+(7.5)	3E(7.5)
Reduction of Toxicity, Mobility, or Volume Through Treatment											
Ranking[d] for reduction of toxicity, mobility, or volume through treatment		★	★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Short-term Effectiveness											
Impacts During Construction	Period of effects to human health and the environment (construction timeframe; years)[e]	n/a	9	9	9	10	10	10	10	11	13
	Diver-assisted dredging (hazardous work duration; diver years)	n/a	n/a	n/a	2	n/a	2	n/a	2	2	12
	Total removal volume / Consumed landfill capacity (cy)[f]	n/a	810,000 / 970,000	810,000 / 970,000	820,000 / 980,000	900,000 / 1,080,000	910,000 / 1,090,000	960,000 / 1,150,000	960,000 / 1,150,000	1,010,000 / 1,210,000	1,080,000 / 1,300,000
	Air quality impacts (CO_2 / PM_{10} emissions; metric tons)	n/a	16,000 / 5.4	16,000 / 5.6	16,000 / 5.9	17,000 / 6.1	18,000 / 6.3	18,000 / 6.4	18,000 / 6.6	19,000 / 7.0	23,000 / 8.3
	Carbon footprint (acre-years)[g]	n/a	3,800	3,800	3,800	4,000	4,300	4,300	4,300	4,500	5,400
Time to Achieve RAOs (years from start of construction)[h]	Human Health – Seafood Consumption (RAO 1 – Risk Ranges)[i]	Does not achieve.	34	9	9	10	10	10	10	11	13
	Human Health – Direct Contact (RAO 2)	Does not achieve.	9	9	9	10	10	10	10	11	13
	Ecological Health – Benthic Organisms (RAO 3)	Not expected to achieve.	39[j]	9	9	10	10	10	10	11	13
	Ecological Health – Fish (RAO 4)	25	9	9	9	10	10	10	10	11	13
Ranking[k] for short-term effectiveness		★	★★	★★★★★	★★★★	★★★★	★★★	★★★★	★★★	★★	★
Implementability											
Ranking[l] for implementability		★★★★★	★★★★	★★★	★★	★★★	★★	★★★	★★	★★	★
Costs											
Total Costs		$950,000	$256,000,000	$264,000,000	$277,000,000	$284,000,000	$297,000,000	$298,000,000	$310,000,000	$326,000,000	$411,000,000
Ranking[m] for costs		★★★★★	★★★★	★★★★	★★★	★★★	★★★	★★★	★★	★★	★

Notes:

a. See Tables 9-5a and 9-5b for other RME risk scenarios.

b. For FS purposes, achievement of RAO 3 is based on at least 98% of predicted surface sediment locations achieving PRGs for all 29 benthic COCs. Compliance with SMS benthic criteria will be determined based on SMS requirements. Predictive modeling was not conducted on all chemicals for the No Action Alternative for compliance of RAO 3. However, it was predicted to exceed for some of those evaluated; therefore, the percentage of surface sediment locations below PRGs are presented for existing conditions (see Table 9-3).

c. The alternatives are ranked relative to other alternatives, with five stars representing the most effective in the long term and most permanent, and one star representing the least effective in the long term and least permanent. The ranking considers the metrics above, summarized as the following two that are considered equally: 1) the magnitude and type of residual risk remaining in the long term, including the risk outcomes and the area with remaining subsurface contamination; and 2) adequacy and reliability of engineering controls, considering the area with remaining contamination on site that will require monitoring and maintenance.

d. The alternatives are ranked relative to the total remediation area in the waterway, with five stars representing use of extensive in situ treatment among the alternatives, and one star representing no use of in situ treatment. Although none of the alternatives employ in situ treatment extensively in the waterway, the highest-ranked alternative is given five stars.

e. Construction timeframe rounded up to the nearest year, and assumes some concurrent removal and material placement (see Table 8-6 for details). As described in Section 8.1.1.8, the Elliott Bay in-water construction window that formally applies in the EW is July 16 to February 15. However, based on recent project experience, the typically permitted in-water construction window is October 1 to February 15 (i.e., 100 days/season). It may be feasible that permitting and tribal coordination will allow for a longer construction window (as large as July 16 to February 15); thus, the upper end of the number of work days in a construction season could increase to around 150 days/season, reducing the total number of years of construction by 2 years, consistently for all action alternatives.

f. The landfill capacity consumed is proportional to the volume of dredged material removed and disposed of in the landfill (assuming a 20% bulking factor).

g. One acre-year represents the amount of CO_2 sequestered by 1 acre of Douglas fir forest for 1 year. Carbon footprint in units of acre-years is appropriate to compare the alternatives differences in CO_2 releases over the entire project.

h. The longest time to achieve among the metrics for four RAOs is presented in this table (see Table 10-1 for detailed times to achieve each RAO). Time to achieve RAOs is based on attaining the PRGs or target risk thresholds, as applicable. Times to achieve RAOs could be reduced if a longer construction window is allowed, as the total number of years of construction could decrease by 2 years, consistently among the action alternatives (see Section 9.1.2.3).

i. Long-term modeling results predict that none of the alternatives will achieve the RAO 1 natural background-based PRG for total PCBs and dioxins/furans. To differentiate among the alternatives, achieving 1×10^{-4} cancer risk for the Adult Tribal RME, 1×10^{-5} cancer risk for the Child Tribal RME, and 1×10^{-4} and 1×10^{-5} cancer risk for the API RME are used as risk reduction milestones for the time to achieve RAO 1 for these two risk driver COCs (see Section 9.1.2.3).

j. Time to achieve RAO 3 PRG based on total PCBs; all other benthic risk driver COCs achieve PRGs immediately after construction completion.

k. The alternatives are ranked relative to each other, with five stars representing the most effective in the short term, and one star representing the least effective in the short term. The ranking considers the metrics above, summarized as the following three categories, which are considered in equal proportion: 1) community and worker protection during construction, which includes the duration of hazardous work (diver-assisted dredging); 2) environmental impacts from construction, including as a result of dredge releases, transportation, consumed landfill capacity, air emissions, energy consumption, and carbon footprint during implementation; and 3) the time to achieve RAOs (as a measure of the residual risk that is present on site until the RAOs are met).

l. The alternatives are ranked relative to each other, with five stars representing the most implementable, and one star representing the least implementable. The ranking considers the following primary metrics equally: 1) technical implementability, with the key differentiating factor being the approach to remediating the technically challenging sediments under the piers; and 2) administrative implementability, with a key differentiating factor being the overall scope of cleanup, which accounts for annual challenges with permitting, fisheries coordination, Port tenant and shipping vessel coordination, and staging.

m. The No Action Alternative is ranked five stars as the least expensive. The action alternatives are ranked relative to each other, with four stars representing the least expensive, and one star representing the most expensive. The action alternatives are grouped based on ranges of costs, using intervals of $30 million each (i.e., $240 to $270 million, $270 to $300 million, $300 to $330 million, and more than $330 million).

Abbreviations:

API – Asian Pacific Islander
ARAR – applicable or relevant and appropriate requirements
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CO_2 – carbon dioxide
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
cy – cubic yards
ENR-nav – enhanced natural recovery used in the navigation channel or berthing areas
ENR-sill – enhanced natural recovery used in the sill reach
EPA – U.S. Environmental Protection Agency
ESD – Explanation of Significant Differences
EW – East Waterway
FS – Feasibility Study
HQ – hazard quotient
LOAEL – lowest-observed-adverse-effect level
MNR – monitored natural recovery
MTCA – Model Toxics Control Act
n/a – not applicable
PCB – polychlorinated biphenyl
PM_{10} – particulate matter less than 10 microns in diameter
PRG – preliminary remediation goal
RAO – remedial action objective
RME – reasonable maximum exposure
ROD – Record of Decision
SMS – Washington State Sediment Management Standards
TRV – toxicity reference value

In the long term, the action alternatives achieve significant risk reduction by relying primarily on removal of contaminated sediment from the EW and using other reliable active remedial technologies, coupled with monitoring and institutional controls to measure and verify long-term risk reduction. The action alternatives are all predicted to achieve PRGs or risk thresholds for RAO 2, 3, and 4. Although none of the action alternatives are predicted to achieve the natural background-based PRGs for RAO 1 for total PCBs or dioxins/furans, all action alternatives are predicted to achieve a similar order of magnitude of risks. For example, 40 years after construction completion, all action alternatives are predicted to achieve a residual total excess cancer risk of 2 or 3 x 10^{-4} for the Adult Tribal seafood consumption RME scenario, 4 or 5 x 10^{-5} for the Child Tribal seafood consumption RME scenario, and 1 x 10^{-4} or 9×10^{-5} for the Adult API seafood consumption RME scenario (see Table 11-1). The No Action Alternative is predicted to achieve RAO 4, but not RAOs 1, 2, or 3.

For RAO 2, all alternatives are predicted to achieve a total excess cancer risk of less than 1×10^{-5}. For arsenic, the action alternatives are predicted to meet the natural-background-based PRG following construction, but increase above the PRG in the long term due to incoming Green River concentrations. The No Action Alternative is not predicted to meet the arsenic PRG.

For RAO 3, the No Action Alternative is not expected to achieve the benthic PRGs. Alternative 1A(12) is predicted to meet benthic PRGs in 99% of point locations 40 years following construction. Alternatives 1B(12) through 3E(7.5) are predicted to meet benthic PRGs in 100% of point locations after construction completion.

For RAO 4, the No Action Alternative does not achieve an HQ less than 1.0 using the lower LOAEL TRV, but does achieve an HQ less than 1.0 using the higher LOAEL TRV. The No Action Alternative is predicted to meet both PRGs within 25 years. All action alternatives are predicted to achieve an HQ less than 1.0 for English sole (using either LOAEL TRV) and for brown rockfish (using the higher LOAEL TRV). An HQ ranging from 1.0 to 1.3 for brown rockfish is achieved using the lower LOAEL TRV (the HQ is greater than 1.0 because of the influence of receiving water PCB concentrations). All action alternatives are predicted to meet the PRGs following construction.

The evaluation of overall protectiveness for short-term effectiveness includes the effects of the alternatives on human health and the environment during the construction phase (the time required to implement the remedy) of the remedial action and the time until RAOs are achieved. Alternatives with larger total sediment removal volumes and longer construction timeframes present proportionately larger impacts to workers, the community, and the environment during implementation. In addition, longer construction periods increase traffic, potential for worker injuries/fatalities, dredge material resuspension and releases, air pollutant emissions, noise, natural resource use, physical disruption of aquatic habitat, and elevated fish and shellfish tissue contaminant concentrations (see Section 10.2.3). In general, the impacts from construction are greatest for dredging, relatively high for capping, and significantly reduced for ENR, in situ treatment, and MNR. Predicted impacts due to construction are generally considered proportional to construction timeframe for the remedial alternatives; however, short-term impacts to workers are expected to be larger for alternatives with diver-assisted hydraulic dredging due to the significant hazards associated with underpier, deep water work. The action alternatives range from 9 to 13 years to construct due to the large scope of dredging for all alternatives—with Alternative 3E(7.5) having the greatest short-term impacts to workers due to the considerable diver-assisted hydraulic dredging in underpier locations, which has intrinsically high safety concerns.

Figure 11-2 presents the summary of model-predicted times to achieve evaluation metrics for the four RAOs for the alternatives. While the No Action Alternative is not predicted to achieve all RAOs, all of the action alternatives are predicted to achieve RAOs. The action alternatives are predicted to achieve PRGs for RAOs 2 through 4 immediately following construction, with the exception of Alternative 1A(12), which is predicted to achieve RAO 3 in 39 years from the start of construction. In addition, all of the action alternatives achieve similar risk reductions for RAO 1, and the time to achieve RAO 1 is expected to be similar for any of the action alternatives.

11.1.2 Compliance with ARARs

Two key ARARs for the EW cleanup are the Washington State SMS (WAC 173-204), which are implemented under MTCA to define how sediment sites meet MTCA, and federal recommended and state surface water quality criteria and standards.

Part V of the SMS (WAC 173-204) is promulgated under MTCA and establishes requirements for remediation of contaminated sediment. The nine action alternatives have been developed in this FS to be compliant with SMS. In particular, SMS (WAC 173-204-560) provides rules for developing cleanup levels considering multiple exposure pathways, background concentrations, and PQLs. The PRGs for RAO 1 for total PCBs and dioxins/furans were developed to be consistent with the rules for cleanup level determination in SMS, but without considering regional background, as it has not been defined for this area (see Appendix A for additional details). All of the action alternatives are expected to comply with MTCA/SMS standards for protectiveness of human health for direct contact (RAO 2), protection of the benthic community (RAO 3), and protection of higher trophic level organisms (RAO 4) by achieving the PRGs or target risk levels for these RAOs, through active remediation, and additional MNR for Alternative 1A(12) only.

For protection of human health for seafood consumption (RAO 1), none of the action alternatives are predicted to achieve the natural background PRGs for PCBs or dioxins/furans, due to model input parameters that assume ongoing contribution of contaminants from diffuse nonpoint sources upstream of the EW. Although the SMS allows for use of a regional background-based cleanup level if it is not technically possible to meet and maintain natural background levels, regional background levels have not yet been established for the geographic area of the EW.

However, CERCLA compliance with MTCA/SMS ARARs may be attained if:

- Post-remedy monitoring demonstrates sediment concentrations are much lower than current model predictions, and PRGs identified in this FS are attained in a reasonable restoration timeframe. If necessary, the restoration timeframe needed to meet the PRGs could be extended by EPA, where consistent with CERCLA. In making such a determination, EPA may take into account the substantive criteria for an SRZ, as provided by the SMS at WAC 173-204-590(3) (see Appendix A).
- SCLs may be adjusted upward if regional background levels are established for the geographic area of the EW. Considering that a regional background value has not yet been determined for the EW, such adjustments could occur in the ROD (before remediation) or subsequently as part of a ROD amendment or

ESD (during or after remediation). Consistent with the bullet above, the restoration timeframe needed to meet the SCLs could be extended by EPA where consistent with CERCLA requirements for a reasonable restoration timeframe.

A final site remedy can be achieved under CERCLA if EPA determines that no additional practicable actions can be implemented under CERCLA to meet certain MTCA/SMS ARARs such that a TI waiver would be warranted for those ARARs under Section 121(d)(4) of CERCLA, 42 U.S.C. § 9621(d)(4)(C).

All of the alternatives must comply substantively with relevant and appropriate state water quality standards and any more stringent recommended federal surface water quality criteria upon completion of the remedial action, except to the extent that they may be formally waived by EPA. While significant water quality improvements are anticipated from sediment remediation and additional source control measures, current upstream Green River and downstream Elliott Bay water concentrations appear to be above federal recommended water quality criteria for some chemicals, and therefore, it is not technically practicable for any alternative to meet all human health federal recommended or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain (e.g., total PCBs and arsenic). If long-term monitoring data and trends indicate that water quality ARARs cannot be met, EPA will determine whether further remedial action could practicably achieve the ARAR. If EPA concludes that an ARAR cannot be practicably achieved, EPA may waive the ARAR on the basis of TI in a future decision document (ROD Amendment or ESD).

11.1.3 Long-term Effectiveness and Permanence

This balancing criterion compares the relative magnitude and type of residual risk that would remain in the EW after remediation under each alternative. In addition, it assesses the extent and effectiveness of the controls that may be required to manage the residual risks from contamination remaining at the site after remediation (see Section 9.1.2.1).

The magnitude of residual risk in surface sediment is the risk predicted to remain on site from exposure to surface sediment contaminant concentrations after the completion of remediation and over time. It was assessed by comparing the predicted outcomes of the alternatives relative to the RAOs. All of the action alternatives are predicted to achieve PRGs (or risk thresholds) for RAOs 2 through 4. For RAO 1, the action alternatives achieve similar risk reductions.

Residual risks were also evaluated from contaminated sediments remaining in the subsurface after remediation (e.g., under caps or in areas remediated by ENR-nav, ENR-sill, in situ treatment, or MNR), which may be exposed in the future through disturbance. All of the action alternatives emphasize removal of contaminated sediments for the majority of the waterway, and thus, have a low potential for subsurface sediment to be exposed. They all include monitoring, maintenance, institutional controls, periodic reviews (e.g., every 5 years), and potential contingency actions to maintain effectiveness over the long term. The subsurface contaminated sediments remaining in place in capped areas have a low potential for exposure because caps are engineered to remain structurally stable under location-specific conditions and provide a high degree of protectiveness. In the context of long-term effectiveness and permanence, the differences among these alternatives are primarily related to the remedial technologies used. In the limited areas that rely on ENR-nav, ENR-sill, in situ treatment, and MNR, residual contaminated sediment has a greater potential for future exposure, as a result of disturbance, and could require more monitoring and potential maintenance, and adaptive management of these areas would trigger contingency actions. In situ treatment is considered more permanent than partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR because in situ treatment permanently binds and reduces the bioavailability of hydrophobic organic compounds (e.g., PCBs) by an estimated 70% (see Section 7.2.7.1). Proposed in situ treatment, partial removal and ENR-nav/ENR-nav, ENR-sill, and MNR areas also represent a relatively small contribution (less than 20%) to the overall EW remedial footprint for alternatives. Removal through diver-assisted hydraulic dredging in underpier areas is also likely to leave contaminated sediment behind due to the presence of riprap slopes and debris.

For long-term effectiveness and permanence, the alternatives are ranked relative to other alternatives, with five stars representing the most effective in the long term and most permanent, and one star representing the least effective in the long term and least permanent. The ranking considers both factors described above, equally: 1) risk reduction achieved by the alternative in the long term and magnitude and type of residual risk remaining; and 2) adequacy and reliability of engineering controls, considering the area of the waterway with contamination permanently removed, and the area with remaining contamination that will require technology-specific monitoring and maintenance, beyond site-wide monitoring.

As shown in Table 11-1, the No Action Alternative ranks the lowest among all alternatives (★) for long-term effectiveness and permanence because it would not reduce risks sufficiently to achieve any of the RAOs, it would leave the largest amount of subsurface contamination in place, and it would not provide reliable controls. All of the action alternatives are considered highly permanent due to a primary reliance on removal (between 80% and 99% of the remediation area undergoes removal or partial removal). Alternative 1A(12) ranks moderate (★★★) because it removes the least amount of contaminated sediment among the action alternatives, has slightly higher residual risks in the long term (due to reliance on MNR), and would leave the largest area without engineering controls (13 acres in underpier areas) to be managed by MNR (the more uncertain technology for underpier); therefore, requiring more intensive monitoring and maintenance and potential contingency actions in the future. Alternatives 1B(12) and 1C+(12) rank relatively higher (★★★★) because they achieve slightly lower risks than Alternative 1A(12) but would remove a similar amount of contaminated sediment as Alternative 1A(12) and have a larger area managed by ENR and in situ treatment. Alternatives 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) rank highest (★★★★★) because they achieve similar risks as other active alternatives, and they rely more on removal than Alternatives 1B(12) and 1C+(12), and are therefore likely to be more permanent. All alternatives include little ENR and limited areas of engineered isolation capping, which is considered highly permanent.

11.1.4 Reductions in Mobility, Toxicity, or Volume through Treatment

This criterion assesses the degree to which site media are treated to permanently and significantly reduce the toxicity, mobility, or volume of site contaminants. The only treatment technology retained for the remedial alternatives is in situ treatment using activated carbon. Activated carbon lowers the mobility of contaminants,[158] reducing the toxicity and bioavailability to biological receptors directly in areas where it is applied and indirectly site-wide through reduced releases to the water column, which lowers average exposure to receptors.

For FS comparison purposes, the reduction of mobility achieved by in situ treatment is proportional to the area that undergoes treatment. The alternatives are ranked relative to each other, with those alternatives with the use of extensive in situ treatment among the alternatives (e.g., > 10 acres) receiving five stars, and alternatives with no in situ treatment receiving one star. As shown in Table 11-1, although none of the alternatives have extensive use of in situ treatment throughout the waterway, Alternatives 1B(12), 1C+(12), 2B(12), 2C+(12), 3B(12), 3C+(12), 2C+(7.5), and 3E(7.5) employ in situ treatment in underpier areas above RALs (varying from 12 to 13 acres) and therefore rank the highest (★★★★★) for this balancing criterion. The No Action Alternative and Alternative 1A(12) have low ranks (★) because they do not treat any contaminated sediment.

11.1.5 Short-term Effectiveness

The evaluation of short-term effectiveness includes the effects of the alternatives on human health and the environment during the construction phase of the remedial action and the time until RAOs are achieved (see Table 11-1 and Figure 11-2). Alternatives with larger removal volumes and longer construction timeframes (particularly alternatives with diver-assisted hydraulic dredging) present proportionately larger risks to workers, the community, and the environment. Longer construction periods increase traffic, potential for worker injuries/fatalities, dredge material resuspension and releases, air pollutant emissions, noise, carbon footprint, consumed landfill capacity, physical disruption of aquatic habitat, and elevated fish and shellfish tissue contaminant concentrations. The construction periods for

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[158] Activated carbon (AC) has been demonstrated to reduce the bioavailability of several contaminants, including PAHs, PCBs, dioxins/furans, DDT, and mercury. For the purpose of modeling, this FS assumes that in situ treatment with AC will reduce bioavailability for hydrophobic organic compounds (e.g., total PCBs, cPAHs, and dioxins/furans) by an estimated 70%, consistent with values measured in the field and laboratory and considering material stability, when applying an AC dose between 3% and 5% (see Section 7.2.7.1).

the action alternatives vary from 9 to 13 years[159]—with Alternative 3E(7.5) having the greatest risks to workers than any of the other alternatives due to the longest overall construction timeframe and considerable duration of underwater removal using divers in underpier areas (12 construction years compared to 0 or 2 years for other action alternatives).

The time to achieve RAOs 2[160] through 4 is equal to the construction duration for all of the action alternatives except Alternative 1A(12), which meets RAO 3 in 39 years from the start of construction. The action alternatives do not achieve PRGs for total PCBs and dioxins/furans for RAO 1, but achieve similar risk reductions. Alternative 1A(12) is predicted to achieve 1 x 10^{-5} order of magnitude cancer risk for Child Tribal RME in a longer timeframe than the other action alternatives (34 years from the start of construction), while the other action alternatives achieve it at the end of construction (9 to 13 years, depending on the alternative). Other RAO 1 risk metrics are predicted to be achieved at the same time by all action alternatives (9 to 13 years, depending on the alternative). The No Action Alternative is predicted to achieve RAO 4 (at year 25), but not RAOs 1, 2, or 3.

For short-term effectiveness, the alternatives are ranked relative to each other, with five stars representing the most effective in the short-term, and one star representing the least effective in the short-term. The ranking balances the considerations discussed above, with the following three summary metrics considered equally: 1) community and worker protection during construction, which includes the duration of hazardous work (diver-assisted dredging); 2) environmental impacts from construction, including as a result of dredge releases, transportation, consumed landfill capacity, air emissions, energy

[159] As described in Section 9.1.2.3, the total number of years of construction could be reduced by about 2 years, consistently across the action alternatives, if a longer construction window is allowed. Therefore, times to achieve RAOs could be reduced compared to those presented here.

[160] Achievement of RAO 2 is based on meeting the PRG for arsenic. All action alternatives are predicted to meet the arsenic RAO 2 PRG of 7 mg/kg dw following construction, but increase above the PRG, due to the incoming Green River concentrations (Section 9.15.1.2). All alternatives, including the No Action Alternative, may meet the PRG in the long term, depending on actual site conditions.

consumption, and carbon footprint during implementation; and 3) the time to achieve RAOs (as a measure of the residual risk that is present on site until the RAOs are met).[161]

As shown in Table 11-1, the No Action Alternative has the lowest ranking (★) for short-term effectiveness because, although it has no impacts associated with construction (as no actions are included in its scope), it is not expected to achieve most of the RAOs. Alternative 3E(7.5) also ranks the lowest (★) because it has: 1) the greatest short-term impacts to human health and the environment during construction, due to the amount of sediment removal (and associated long construction timeframe); 2) the highest potential for work-related accidents (due to extensive use of diver-assisted hydraulic dredging [12 construction years] in underpier areas), which poses substantial health and safety risks to remediation workers; and 3) the longest time to achieve RAOs among the active alternatives. Alternative 1A(12) ranks relatively low (★★) because, although it has the lowest construction-related impacts of the action alternatives, it takes longer to achieve RAO 3 and the 1 x 10^{-5} order of magnitude risk for Child Tribal RME, compared to the other action alternatives, due to some reliance on MNR. Alternative 2C+(7.5) also ranks relatively low (★★) because of moderately more construction impacts compared to the action alternatives (11 years of construction and 2 years of diver-assisted hydraulic dredging) and moderately longer time to achieve RAOs (11 years). Alternatives 2C+(12) and 3C+(12) have a moderate ranking (★★★) due to the moderate construction impacts to human health and the environment (10 years of construction, including 2 years of diver-assisted hydraulic dredging, and removal of 910,000 and 960,000 cy of sediment), and moderate time to achieve RAOs (following 10 years of construction). Alternatives 1C+(12), 2B(12) and 3B(12) are ranked relatively higher (★★★★) due to lower construction impacts to human health and the environment (by requiring 10 years of construction and no diver-assisted hydraulic dredging, and removal of 900,000 to 960,000 cy of sediment from the waterway), and having a moderately shorter time to achieve RAOs (immediately post-construction). Alternative 1C+(12) also scores relatively higher (★★★★) by having a shorter construction timeframe (9 years), removing less total sediment (820,000 cy), and having a shorter time to achieve RAOs (9 years), but also includes 2 years

[161] Times to achieve RAOs could be reduced if a longer construction window is allowed, as the total number of years of construction could decrease by about 2 years, consistently across the action alternatives (Section 9.1.2.3). However, the total number of construction days and associated construction impacts would remain unchanged.

of diver-assisted hydraulic dredging. Alternative 1B(12) ranks highest (★★★★★) by having the least construction impacts among the alternatives (9 years of construction, no diver-assisted hydraulic dredging, and removal of 810,000 cy of sediment), and achieving RAOs immediately following construction.

11.1.6 Implementability

Technical implementability and administrative implementability are factors considered under this criterion for the EW OU. Technical implementability encompasses the complexity and uncertainties associated with the alternative, the reliability of the technologies, the ease of undertaking potential contingency remedial actions, and monitoring requirements. Administrative implementability includes the activities required for coordination with other parties and agencies (e.g., consultation, or obtaining permits for construction activities). The No Action Alternative has no implementability challenges, while the action alternatives represent large, complex remediation projects with many technical and administrative challenges.

The technical implementability challenges are similar across the action alternatives in open-water areas, but are different across these alternatives in underpier areas. Alternative 1A(12) has few technical challenges associated with MNR in underpier areas (only those related to monitoring and potential contingency actions) and low potential for difficulties and delays and impacts to EW tenants and users. The other action alternatives have moderate technical challenges associated with placing in situ treatment material in underpier areas. Alternatives 2C+(12), 3C+(12), 2C+(7.5), and 3E(7.5) have large technical challenges associated with diver-assisted hydraulic dredging under piers. This form of dredging is more difficult to implement than the other technologies, particularly in underpier areas of EW, due to work conducted in deep water with low visibility and presence of suspended sediments, variable conditions under piers (e.g., presence of debris, cables, large wood, and broken pilings), potential prolonged impacts and delays to vessel operations (related to diving schedules), extensive dewatering requirements, and water management operations.

For administrative implementability, all underpier technologies (MNR, in situ treatment, and diver-assisted hydraulic dredging) will be monitored following construction and have the possibility for future contingency actions if remediation goals are not met. In addition, Alternatives 1A(12), 1B(12), and 1C+(12) have a higher potential for future contingency actions in open-water areas because of ENR-nav in the navigation channel.

An administrative feasibility factor for the EW is that in-water construction is not allowed year-round, in order to protect juvenile salmon and bull trout migrating through the EW (see Section 8.1.1.8). Because the EW is a busy working industrial waterway and is also used by tribes for a commercial salmon netfishery, coordination is necessary with EPA, National Marine Fisheries Service, U.S. Fish and Wildlife Service, the tribes, Port tenants, and other waterway users to ensure that disruptions of their activities are minimized during remediation. This feasibility factor affects all the action alternatives similarly, generally proportional to the construction timeframe for the alternatives.

In addition, navigation channel reauthorization is an administrative challenge for some alternatives. Alternatives 1A(12), 1B(12), 1C+(12), 2B(12), 2C+(12), and 2C+(7.5) include partial dredging and capping in the Shallow Main Body – South CMA, which would require the federal navigation channel to be reauthorized to shallower depths in that area to accommodate capping.

For implementability, the alternatives are ranked relative to each other, with five stars representing the most implementable, and one star representing the least implementable. The ranking considers two primary metrics equally: 1) technical implementability, with the key differentiating factor being the approach to remediating the technically challenging sediments under the piers; and 2) administrative implementability, with the key differentiating factor being the overall complexity of the cleanup, which accounts for annual challenges of permitting, fisheries coordination, Port tenant and shipping vessel coordination, and staging.

As shown in Table 11-1, Alternative 3E(7.5) receives the lowest rank (★) for implementability relative to the other alternatives, largely due to technical challenges associated with 12 construction seasons of diver-assisted hydraulic dredging over large areas of underpier sediment, placement of in situ treatment material under the piers, and has the largest overall scope of the alternatives (13 years of construction). Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5) receive a relatively low ranking (★★) because they employ some diver-assisted hydraulic dredging followed by in situ treatment under the piers and have moderate overall scope of remediation (9 to 11 years). Alternatives 1B(12), 2B(12), and 3B(12) are considered moderately implementable (★★★) because they include in situ treatment performed in underpier areas (which is significantly more implementable than diver-assisted hydraulic dredging) and have moderate overall scope of remediation (9 to 11 years). Alternative 1A(12), while having similar construction aspects in open water to Alternatives 1B(12) and 3B(12), scores the highest among the action alternatives (★★★★) because of the high implementability of performing MNR under the piers and a moderately lower overall scope (9 years of construction). The No Action Alternative is given the highest implementability rank (★★★★★) because it has no construction elements and no provisions to trigger contingency actions.

11.1.7 Cost

Figure 11-3 depicts the costs for the remedial alternatives plotted with the remedial technology areas. The No Action Alterative is ranked five stars as the least expensive. The action alternatives are ranked relative to each other, with four stars representing the least expensive and one star representing the most expensive. The action alternatives are grouped based on ranges of costs using intervals of $30 million each (i.e., $240 to $270 million, $270 to $300 million, $300 to $330 million, and more than $330 million). As shown in Table 11-1, Alternative 3E(7.5) has the highest cost ($411 million), and therefore ranks lowest (★) for this criterion. Alternatives 3C+(12) and 2C+(7.5) are assigned low-moderate ranking (★★) with costs of $310 and $326 million, respectively. Alternatives 1C+(12), 2B(12), 2C+(12), and 3B(12) receive a moderate ranking (★★★), with costs ranging from approximately $277 to $298 million. Alternatives 1A(12) and 1B(12) receive a relatively high ranking, with costs of approximately $256 and $264 million (★★★★). The No Action Alternative has the lowest cost ($950,000) and, therefore, has the highest ranking (★★★★★) for this criterion.

11.1.8 Cost-effectiveness

A statutory requirement that must be addressed in the ROD and supported by the FS is that the remedial action must be cost-effective (40 CFR § 300.430(f)(1)(ii)(D)). Cost-effectiveness is the consideration of both the costs and the benefits (or “overall effectiveness”) for the remediation alternatives. The cost-effectiveness determination should carefully consider the relative incremental benefits and costs between the alternatives. In accordance with the National Contingency Plan, the cost of the selected remedy must not be greater than less costly alternatives that provide an equivalent level of protection (EPA 1999). For the cost-effectiveness evaluation, benefits were assessed using long-term effectiveness and permanence and short-term effectiveness. Figure 11-4 depicts overall effectiveness metric (including long-term and short-term effectiveness metrics) and costs for the alternatives.

The least costly action alternative, Alternative 1A(12), does not rank as highly for overall effectiveness compared to the other action alternatives, primarily due to increased time to achieve RAOs and slightly higher risks compared to the other action alternatives. Moreover, the cost savings for this alternative are not commensurate with the decreased overall effectiveness for the alternative. While the most costly alternative, Alternative 3E(7.5), results in the largest removal volume, it does not provide a commensurate improvement in overall effectiveness relative to the other action alternatives (i.e., there is no appreciable reduction in site-wide risks). Further, the incremental cost of this alternative relative to the next most costly alternative ($85 million) is disproportionate to any additional environmental benefits achieved.

The rest of the action alternatives (Alternatives 2B(12) through 2C+(7.5)) have similar overall effectiveness, with the alternatives with only in situ treatment under the piers (Alternatives 1B(12), 2B(12), and 3B(12)) ranking higher for short-term effectiveness than the alternatives that include diver-assisted hydraulic dredging (Alternatives 1C+(12), 2C+(12), 3C+(12), and 2C+(7.5)). The benefits among these alternatives (particularly those related to human health risk reduction) do not increase with higher costs; therefore, lower-cost alternatives are preferred because they tend to be more cost-effective.

11.2 Risk Management Principles and National Guidance

The EW is one of many large and complex contaminated sediment sites in the country. Many sites in other regions are addressing similar issues and uncertainties. In response, EPA released the *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002a), which can be found in Appendix A of the *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005). This FS process developed and evaluated the alternatives for the EW in a manner consistent with these documents, most specifically with the 11 risk management principles set forth below:

1. **Control Sources Early:** Source control in the EW OU has been ongoing under applicable federal and state regulations (e.g., Clean Water Act). Source tracing and control efforts include ongoing source tracing sampling, operating and maintaining SD and CSO systems, complying with NPDES permits, implementing County and City CSO Control Plans, inspecting local businesses and implementing BMPs, and conducting upland cleanups. Empirical data and modeling efforts to date suggest that the effects of lateral loadings should be localized for current and future loading from lateral sources (e.g., SDs and CSOs). In addition, data and modeling have identified that broader regional inputs from upstream and from atmospheric sources will affect the long-term surface sediment concentrations in the EW.
2. **Involve the Community Early and Often:** Stakeholders were engaged as early as the development of the scope of work and through the duration of the project. The baseline risk assessments evaluated potential site uses by workers and local populations, including tribal members and Asian and Pacific Islanders. These risk results have been factored into developing the long-term cleanup goals for the EW. EPA will consider input from the affected community on the FS and when developing the Proposed Plan.
3. **Coordinate with States, Local Governments, Tribes, and Natural Resource Trustees:** The Muckleshoot and Suquamish Tribes, DNR, and NOAA have all been closely involved in the studies completed to date on the EW. EWG, which includes three local government agencies, will continue to share key concepts and issues related to the cleanup with NOAA, the tribes, and DNR.
4. **Develop and Refine a Conceptual Site Model that Considers Sediment Stability:** Empirical data and modeling have been used to develop a CSM of the EW, which is summarized in Section 2 and described in detail in the SRI (Windward and Anchor QEA 2014). The CSM indicates that the EW is a net depositional system, with areas subject to episodic scouring as a result of vessel activity within routine operating parameters, but not from estuarine flows. Potential vessel scour depths were considered in developing the remedial footprint, assigning remedial technologies, and predicting the performance of remedial alternatives.

5. **Use an Iterative Approach in a Risk-based Framework:** Studies by the NRC (2007) and other independent, scientific peer reviews of sediment sites throughout the country (USACE 2008a; Cannon 2006) conclude that substantial uncertainties exist related to cleanup of complex sites such as the EW and point to the necessity of using adaptive management strategies. The action alternatives all include monitoring and potential contingency actions as needed to achieve RAOs.
6. **Evaluate the Assumptions and Uncertainties Associated with Site Characterization Data and Site Models:** A complex study, completed over the past 8 years, has been conducted and includes extensive site characterization and models for evaluating sediment stability and long-term recovery in the EW. Key uncertainties have been considered in evaluating the alternatives, and the effects of these uncertainties have been discussed in the evaluation of alternatives.
7. **Select Site-specific, Project-specific, and Sediment-specific Risk Management Approaches that Will Achieve Risk-Based Goals:** This principle summarizes the approach used in this FS. EW OU-specific risk-based goals have been developed. A range of remedial alternatives have been developed that consider location-specific uses, physical constraints, and the limitations of the remedial technologies. Finally, those alternatives have been compared to risk-based goals and background levels to help develop risk management approaches that include a range of actions. The action alternatives include a combination of technologies to look at the most effective ways to manage risk, and also include monitoring and adaptive management to maintain reduction in risks in the long-term.
8. **Ensure that Sediment Cleanup Levels are Clearly Tied to Risk Management Goals:** The RAOs developed for the EW are based on the results of the baseline human health and ecological risk assessments (Windward 2012a, 2012b). The sediment PRGs associated with each RAO are based on the results of the risk assessments or ARARs. The alternatives share the same PRGs and ultimately have the same risk management goals. Long-term sediment and fish tissue concentrations will be measured as part of site-wide monitoring for the action alternatives to assess remedy effectiveness.
9. **Maximize the Effectiveness of Institutional Controls and Recognize Their Limitations:** To be fully protective, the selected remedy will require institutional controls. Seafood consumption advisories are expected to continue indefinitely under all of the alternatives because background levels are predicted to result in risks exceeding

thresholds. Seafood tissue contaminant concentrations are predicted to increase in the short term as a result of dredging. Many studies have shown seafood consumption advisories to be of limited efficacy. Recommended actions for public education, outreach, and notification control elements are the same for the action alternatives. The no action alternative does not include institutional controls for managing residual risks beyond the existing WDOH seafood consumption advisory. Monitoring and notification of waterway users is essential where contamination remains in place following remediation (particularly the containment-focused alternatives, in areas where capping has been utilized). Such controls have been successfully implemented at a wide range of sites regionally and nationally.

10. **Select Remedies that Minimize Short-term Risks while Achieving Long-term Protection:** the action alternatives include various combinations of remediation technologies. This allows each alternative's performance to be compared with respect to short-term risks and long-term protection. Although all the alternatives achieve similar long-term risk-reduction goals, the time to achieve these goals is different. Conversely, short-term risks to the community and workers and environmental impacts are closely tied to the construction period and remedial technologies used for each alternative. Short-term risks during construction include worker safety, transportation-related impacts on communities, air emissions, habitat disruption, and elevated contaminant concentrations in resident fish and shellfish tissue during and a few years following dredging.
11. **Monitor During and After Sediment Remediation to Assess and Document Remedy Effectiveness:** the action alternatives include extensive short-term and long-term monitoring programs to assess effectiveness, and the cost estimates assume contingency actions based on monitoring results. The No Action Alternative includes long-term site-wide monitoring but does not assume any contingency actions based on the latter monitoring.

11.3 Managing the Key Uncertainties

Decision-making on a site of the size and complexity of the EW requires careful consideration of uncertainties in the FS data and analyses. The uncertainties associated with the EW FS are similar to other large sediment remediation sites. Many of the uncertainties in this FS affect all alternatives to a similar degree and therefore do not significantly affect the relative comparison of alternatives. A sensitivity analysis was performed for the FS to understand the impacts of key parameters on the performance of the alternatives. For Alternatives 2B(12) through 3E(7.5) (all of the action alternatives with the exception of Alternative 1A(12)), the range of predicted SWACs between the alternatives was smaller than the range of predicted SWACs between sensitivity runs for a single alternative, with no change in risk outcome for any sensitivity run (Figure 11-5). The following factors emerge as particularly important for managing uncertainty relative to the anticipated performance of the alternatives:

- Predictions of average surface sediment contaminant concentrations are greatly influenced by a number of factors related to incoming sediment concentrations, vessel scour, sediment remaining adjacent to structures, and dredge residuals. Sediment mixing can increase or decrease sediment concentrations in the EW, depending on the concentrations that are being mixed. Dredge residuals thickness, concentration, and distribution will vary as a result of quality and thickness of sediment being dredged, hydrodynamic and operational conditions during construction, and BMPs employed. The presence of dredge residuals will be mitigated to the extent practicable by using BMPs and implementing an adaptive management framework to monitor and perform contingency actions as necessary to minimize the impact of residuals.
- As a result of the large amounts of relatively clean sediments from Green River upstream that deposit within the EW, surface sediment contaminant concentrations are predicted to converge to levels similar to the quality of incoming sediment from the Green River (general urban inputs from EW laterals and the LDW laterals and resuspended bedded sediment are expected to have very little impact on predicted SWAC values, based on the total mass of loads to the EW from these two sources (0.7%) compared to other upstream sources (i.e., Green River sediments), resulting in similar levels of risk over time among the action alternatives. The concentrations of these inputs are uncertain and will change over time in response to many factors, including upstream cleanups, upstream source control, and source control in the EW drainage basin.
- Technical challenges associated with the technologies for remediating underpier areas are a key uncertainty in this FS.
  - The performance of MNR in underpier areas is less certain compared to the other remedial technologies; however, MNR poses very few technical challenges.

- The performance of in situ treatment depends on many site-specific complex physical and chemical factors, and constructability of the in situ treatment technology includes important technical challenges for placing material on steep slopes in difficult-to-access areas (due to the presence of the supporting piles and the low overhead clearance under the pier deck surfaces). Another potential uncertainty relates to sediment stability and the location and amount of exchange of material with open-water areas with regard to potential for recontamination of adjacent areas. However, underpier areas have relatively small spatial extent and, therefore, are expected to contribute less to site-wide risks from bioaccumulative compounds, as shown in model predictions (see Section 9.15.1.2).
- Finally, diver-assisted hydraulic dredging is associated with large uncertainty with both performance and technical implementability. Performance is uncertain with respect to the quantity of contaminated sediment that will be left behind due to conditions under piers (e.g., riprap interstices and debris). However, diver-assisted hydraulic dredging has less uncertainty related to exchange of sediment with open-water areas, compared to in situ treatment alone, because there is less sediment available for exchange. Technical implementability is also uncertain with respect to the construction timeframe and costs associated with removing underpier sediments in deep water with low visibility from presence of suspended sediments and variable conditions under piers (e.g., presence of debris, cables, large wood, and broken pilings). Underpier work has the potential for prolonged impacts and delays from vessel operations. Extensive dewatering and water management operations are associated with hydraulic dredging. Substantial health and safety risks are posed by this type of underwater construction and management of those risks can slow the implementation or limit the areas that can be safely dredged by divers.

- The performance of the remedial technologies outside of underpier areas also have uncertainties, which are mitigated by adaptive management.
  - Dredging results in the release of contaminants to the water column (which can maintain elevated fish and shellfish tissue contaminant concentrations over the short term) and dredge residuals to the sediment surface. As described in Appendix A, full removal of all contaminated sediment is not possible in many

areas near structures, where setbacks and stable slopes required for structure protection will leave some contaminated sediments behind. Long-term site-wide predictions will depend on the location and amount of sediment remaining adjacent to structures, and the potential for it to be disturbed from propwash.

- Capping, ENR, and in situ treatment require ongoing monitoring and may need periodic maintenance. MNR performance may be slower or faster than predicted and may require additional monitoring or potential contingency actions. These uncertainties would be managed in the long term under the action alternatives by the required monitoring, contingency actions, and repairs as needed. Cost estimates in this FS include the costs of these long-term management activities. These activities would be enforceable requirements under a Consent Decree (or similar mechanism), and EPA is required to review the effectiveness of their selected remedy no less frequently than every 5 years.

- Uncertainty exists in the predictions of resident seafood tissue contaminant concentrations and associated human health risks for total PCBs and dioxins/furans following remediation. This uncertainty is driven by: 1) exposure assumptions from the human health risk assessment; 2) assumptions used in the food web model for total PCBs such as uptake factors and future water concentrations; and 3) uncertainties in biota-sediment accumulation factors used for dioxins/furans (see Section 8.3.2 of the EW SRI, Windward and Anchor QEA 2014) The predictions of resident seafood tissue contaminant concentrations and risks are nevertheless useful for comparing the alternatives to one another because the uncertainties are the same for all alternatives, and therefore all of the alternatives should be affected similarly.

These types of uncertainties were addressed by bounding and uncertainty analyses to understand their potential effects. Overall, predicted average surface sediment concentrations after remediation are more affected by uncertainty factors (e.g., chemistry of Green/Duwamish River sediments and net sedimentation rates) than by expected differences associated with the remedial alternatives themselves. However, this analysis is performed using a common set of assumptions for all alternatives to demonstrate the potential differences among alternatives. Most effects are consistent across alternatives, and therefore, the relative comparison of alternatives is still appropriate to assess cleanup alternatives.

11.4 Next Steps

EPA and EWG will solicit input from the public, including stakeholders, such as tribes and other trustees, to be incorporated into the final FS. EPA will issue a Proposed Plan that identifies a preferred remedial alternative for the EW. Formal public comment will be sought on the Proposed Plan. After public, state, and tribal comments on the Proposed Plan are received and evaluated, EPA will select the final remedy and issue the ROD. The cleanup standards, objectives, and RALs will be specified in the ROD, which is anticipated to be issued with state concurrence. The ROD may also specify final post-construction goals for some or all remediated areas. After the ROD is issued, the first 5-year period is expected to include conducting source control activities as needed; negotiating one or more consent decrees for performance of remedial design and cleanup; conducting predesign investigations, baseline monitoring, and remedial designs; and developing a compliance monitoring program for active cleanup areas. The long-term monitoring plan will be designed to assess achievement of RAOs, evaluate performance of the cleanup, and trigger contingency actions and adaptive management steps as needed.

11.4.1 Ongoing Source Control Efforts

The EW source control approach focuses on controlling contamination that affects EW sediments. It is based on the principles of source control for sediment sites described in *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002a) and similar Washington State requirements. EWG coordinates and implements source control efforts in the EW and works in cooperation with local jurisdictions, Ecology, and EPA to implement source control actions.

It is important to note that in localized areas, some recontamination may occur even with aggressive source control because of the difficulty in identifying and completely controlling all potential sources of certain ubiquitous contaminants that are widely released by urban activities (e.g., phthalates). Other contaminants with the possibility of exceeding action levels near outfalls based on the FS analysis include 1,4-dichlorobenzene, dioxins/furans, and mercury. For the EW, recontamination of EW sediments will be controlled to the extent practicable under existing source control efforts and authorities. The goal is to limit sediment recontamination that exceeds location-specific standards, where feasible.

EPA's (2002a) sediment guidance recommends "control sources early, before sediment cleanup begins," but that may not always be practical. Delaying sediment cleanup until all sources have been identified and controlled, regardless of their contribution in terms of contaminant loading, may delay achieving many of the benefits that sediment cleanup alone can accomplish. The EW source control efforts have been performed in parallel with the SRI and FS and will continue before, during, and after the implementation of the remedy. Source tracing and control efforts include:

- Conducting ongoing source tracing sampling
- Operating and maintaining storm drain and CSO systems
- Complying with NPDES permits
- Implementing County and City CSO Control Plans
- Inspecting local businesses that discharge or otherwise contribute to storm drains and CSOs to ensure that they are implementing appropriate BMPs to reduce the amount of pollution discharged from their property
- Conducting upland cleanups and monitoring to protect sediments from contaminated soils and groundwater

Because of the dynamic nature of many source control activities and the understanding of recontamination potential over time, it is essential to maintain flexibility when adapting source control efforts to specific needs within source control areas. The success of source control depends on cooperation of all relevant parties and the active participation of businesses that must make changes to accomplish source control goals. This adaptive strategy for prioritizing source control work will continue throughout selection, design, and implementation of the long-term remedy for the EW.

11.4.2 Adaptive Management for In-Water Sediment Remediation

Remediation of contaminated sediments in the EW under CERCLA should be undertaken in a flexible, iterative, and adaptive manner. Actions should be adjusted based on what has been learned from other cleanups and previous construction activities. The cleanup process of the EW should do the following:

1. Continue source control efforts, sequenced to the sediment remediation.
2. Address uncertainties and provide flexibility in the design elements as more data become available. Use the results of previous actions, including actions at adjacent sites to inform further sediment cleanup.
3. Monitor performance and changing conditions in both the remediation and source control efforts.
4. Implement contingency actions that may become needed over time.

Experience at other complex sediment sites points to the necessity of using adaptive management strategies, as recommended by EPA guidance (EPA 2005), the NRC (2007), and other independent, scientific peer reviews of sediment sites throughout the country (USACE 2008a; Cannon 2006). For adaptive management to work effectively, it must be informed by data. Further actions can be adjusted based on what has been learned from previous construction seasons. A long-term monitoring plan will be established with metrics and analyses that meet clearly articulated data quality objectives. Baseline monitoring will be conducted prior to beginning the initial remedial activities to establish a benchmark for evaluating the effectiveness of the remediation. Collecting monitoring information during and after cleanup will help evaluate the effectiveness of the selected remedial alternative, and trigger the planning and execution of contingency actions as needed. Because remediation and source control efforts will take years to occur, and biological response may take even longer, monitoring the changes in contaminant inputs and responses of various media in the EW will be important to help determine when and to what extent contingency actions may be needed. Contingency actions may include more sediment remediation or source control efforts.

In the EW, adaptive management could be used to maximize the rate at which site-wide risks are reduced, while minimizing the uncertainties associated with remediation. In particular, remediation of underpier sediments, which represent a relatively small area (12 acres), have more uncertainty associated with performance and/or implementability for all retained remedial technologies (MNR, in situ treatment, and diver-assisted hydraulic dredging). In particular, diver-assisted hydraulic dredging is more hazardous for worker health and safety and likely to have high costs and short-term impacts that are disproportionate to the long-term benefits (i.e., reduction in risk) due to the significant amount of contaminated sediment that will remain following diver-assisted dredging (see Section 7.2.6.3). For these reasons, adaptive management principles will be particularly important for remediating underpier sediments in effective and practicable ways.

EPA will evaluate the effectiveness of the selected remedial alternative every 5 years subsequent to completion of remediation. The 5-year reviews will integrate comprehensive evaluations of the seafood consumption advisories, outreach and education programs, source control work, remedy effectiveness, and changes in overall waterway health. These periodic reviews can be used by EPA in conjunction with the performance monitoring program to identify the need for any additional course corrections (e.g., contingency actions, review endpoints, modify technologies, or conduct more monitoring) in the cleanup.

	Achieve Threshold Criteria?	Long-term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-term Effectiveness	Implementability	Cost
No Action	No	Low	Low	Low	Very high	Very high
1A(12)	Yes	Moderate	Low	Low-moderate	Relatively high	Relatively high
1B(12)	Yes	Relatively high	Very high	Very high	Moderate	Relatively high
1C+(12)	Yes	Relatively high	Very high	Relatively high	Low-moderate	Moderate
2B(12)	Yes	Very high	Very high	Relatively high	Moderate	Moderate
2C+(12)	Yes	Very high	Very high	Moderate	Low-moderate	Moderate
3B(12)	Yes	Very high	Very high	Relatively high	Moderate	Moderate
3C+(12)	Yes	Very high	Very high	Moderate	Low-moderate	Low-moderate
2C+(7.5)	Yes	Very high	Very high	Low-moderate	Low-moderate	Low-moderate
3E(7.5)	Yes	Very high	Very high	Low	Low	Low

- Ranks very high compared to other alternatives
- Ranks relatively high compared to other alternatives
- Ranks moderate compared to other alternatives
- Ranks low-moderate compared to other alternatives
- Ranks low compared to other alternatives

Notes:

Low costs are given a high rank, and high costs are given a low rank.

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act

Figure 11-1
CERCLA Comparative Analysis of Alternatives
Feasibility Study
East Waterway Study Area

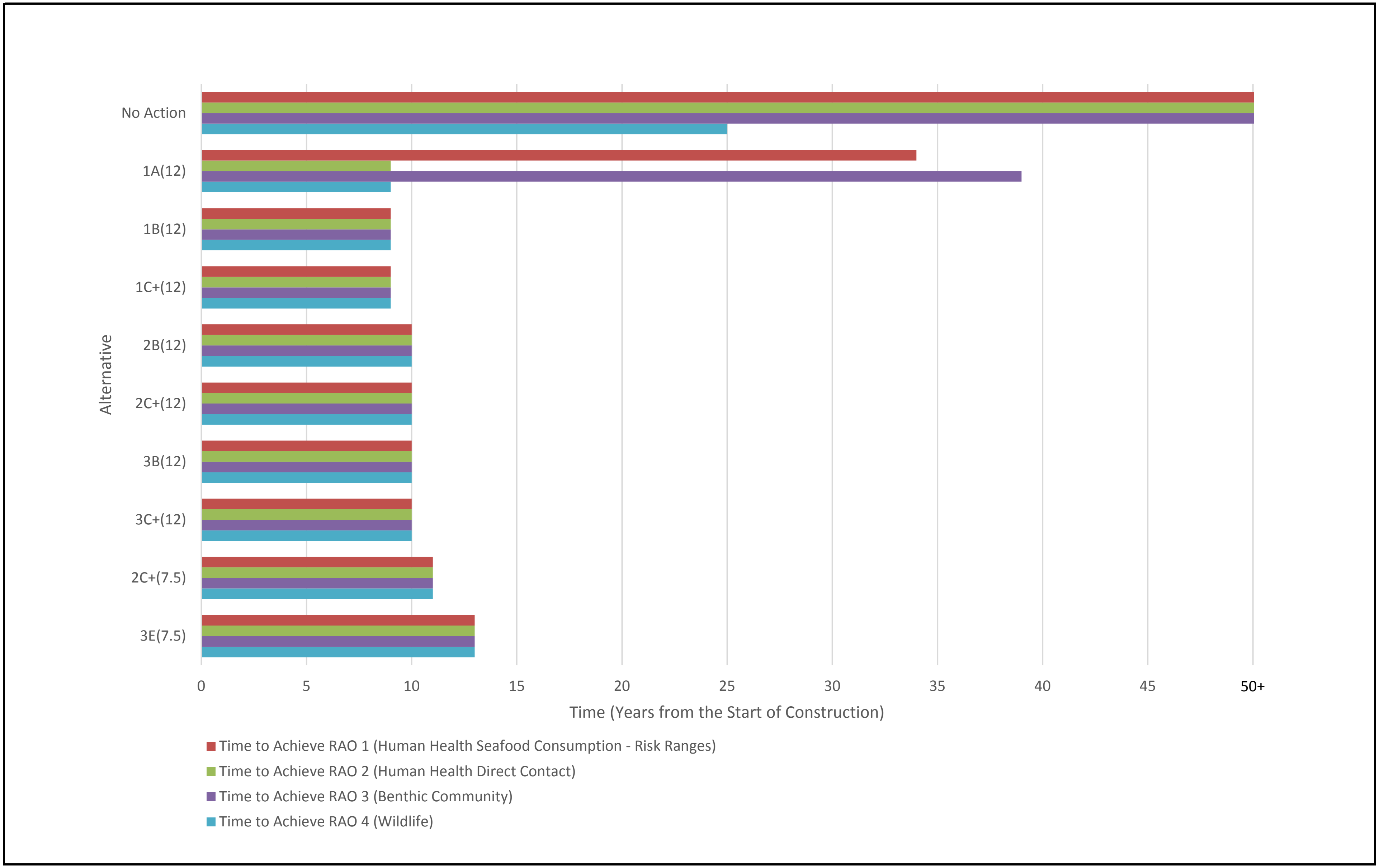
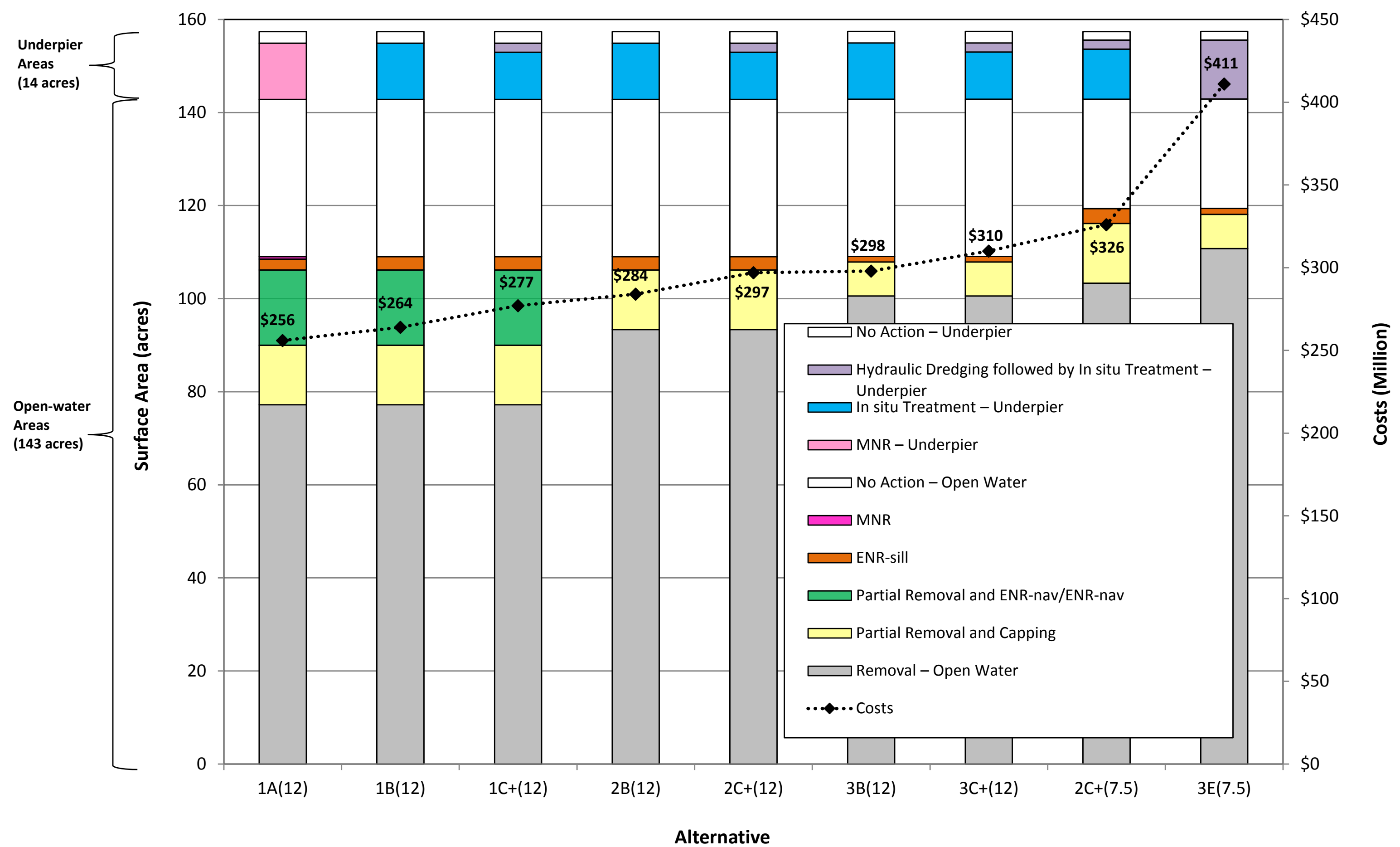


Figure 11-2
Time to Achieve Remedial Action Objectives
Feasibility Study
East Waterway Study Area



Notes:

1. The total East Waterway Operable Unit surface area is 157 acres.
2. Removal - Underpier is diver-assisted hydraulic dredging.
3. ENR-sill is enhanced natural recovery applied in the Sill Reach.
4. ENR-nav is enhanced natural recovery applied in the navigation channel and deep-draft berthing areas.

ENR = enhanced natural recovery; MNR = monitored natural recovery

Figure 11-3
Costs and Remediation Areas for the Action Alternatives
Feasibility Study
East Waterway Study Area

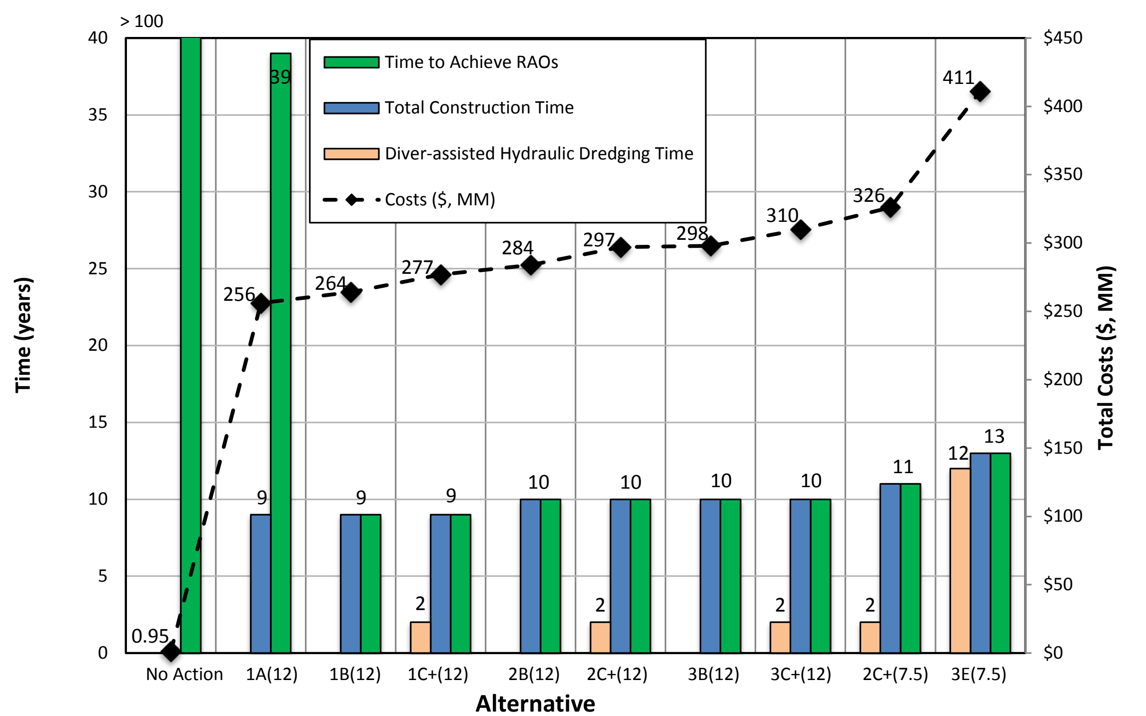
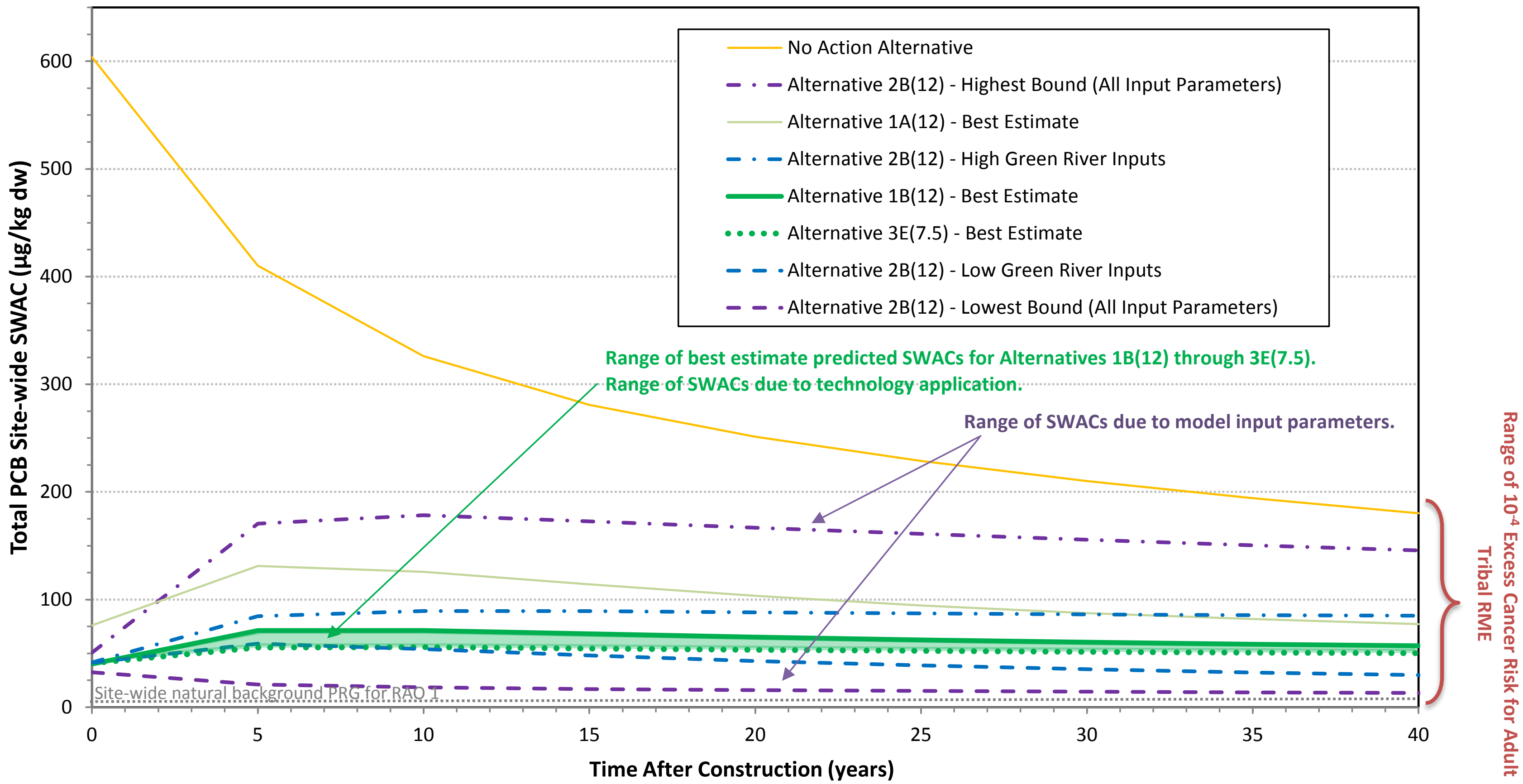


Figure 11-4
Overall Effectiveness and Costs for Alternatives
Feasibility Study
East Waterway Study Area



Notes:

µg/kg = microgram per kilogram; dw = dry weight; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration

Figure 11-5

Predicted Site-wide Total PCB SWACs Over Time for Action Alternatives

Feasibility Study

East Waterway Study Area

12 REFERENCES

AECOM, 2012. Feasibility Study, Lower Duwamish Waterway, Seattle, Washington. Final Report. Prepared for Lower Duwamish Waterway Group. October 2012.

Alcoa (Alcoa Inc.), 2006. Draft Remedial Options Pilot Study Documentation Report. Volume 1. Grasse River Study Area. Massena, New York. May 2006.

Alcoa, 2010. Activated Carbon Pilot Study 2008 Monitoring Results Summary Report. Grasse River Study Area, Massena, New York. Prepared by Anchor QEA Engineering, PLLC, ARCADIS, and the University of Maryland Baltimore County. February 2010.

Amec Foster Wheeler, 2015. Sediment Sampling Beneath Pier 36B Data Report. U.S. Coast Guard Base Seattle, Seattle, Washington. Prepared for U.S. Coast Guard, Civil Engineering Unit Oakland, Oakland, California. July 2015.

Anchor (Anchor Environmental, L.L.C.), 2000. Preliminary Draft Disposal Site Alternatives Evaluation, EW Deepening Project. Prepared for Port of Seattle. August 9.

Anchor and Battelle (Anchor Environmental, L.L.C. and Battelle), 2008. Final Sediment Transport Evaluation Approach Memorandum (STEAM), East Waterway Operable Unit, Supplemental Remedial Investigation/Feasibility Study. Prepared for Port of Seattle. December.

Anchor and Windward (Anchor Environmental, L.L.C. and Windward Environmental LLC), 2005. Phase 1 Removal Action Completion Report, East Waterway Operable Unit. Prepared for Port of Seattle. September 2005.

Anchor and Windward, 2007. Final Workplan, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Prepared for Port of Seattle. July 2007.

Anchor and Windward, 2008a. Final Existing Information Summary Report (EISR), East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Prepared for Port of Seattle. March 2008.

Anchor and Windward, 2008b. Final Source Control Evaluation Approach Memorandum (SCEAM), East Waterway Operable Unit Supplemental Remedial Investigation/ Feasibility Study. Prepared for Port of Seattle. June 2008.

Anchor QEA (Anchor QEA, LLC), 2009. Final Sediment Transport Characterization Quality Assurance Project Plan (STC QAPP). East Waterway Operable Unit, Supplemental Remedial Investigation/Feasibility Study. Prepared for Port of Seattle. March.

Anchor QEA, 2011. Terminal 4 Confined Disposal Facility Design Analysis Report (Prefinal 60% Design Deliverable). Prepared for the Port of Portland.

Anchor QEA, 2012a. Final Remedial Alternative and Disposal Site Screening Memorandum (Screening Memo), East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Prepared for Port of Seattle. October 2012.

Anchor QEA, 2012b. Field Investigation Report, Terminal 25S Site Investigation. Prepared for Port of Seattle. December 2012.

Anchor QEA and Arcadis, 2010. Phase 1 Evaluation Report: Hudson River PCBs Superfund Site. Prepared for General Electric Company. March.

Anchor QEA and Coast & Harbor Engineering, 2012. Final Sediment Transport Evaluation Report (STER), East Waterway Operable Unit Supplemental Remedial Investigation/ Feasibility Study. Prepared for Port of Seattle. August 2012.

Anchor QEA and Windward, 2009. Final Source Control Evaluation and Data Gaps Memorandum (SEDGM), East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Prepared for Port of Seattle. December 2009.

Atwater, B.F., and A.L. Moore, 1992. A Tsunami about 1000 Years Ago in Puget Sound, Washington. In: *Science*, v.258, pp. 1614-1617, 1992.

Barrick, R., S. Becker, L. Brown, H. Beller, and R. Pastorok, 1988. Sediment Quality Values Refinement: Volume I. 1988. Update and evaluation of Puget Sound AET. Prepared for Puget Sound Estuary Program (PSEP), U.S. Environmental Protection Agency, Region 10. PTI Environmental Services, Inc., Bellevue, Washington.

Bauman, P.C., and J.C. Harshbarger, 1998. Long-term Trends in Liver Neoplasm Epizootics of Brown Bullhead in the Black River, OH. In: Environmental Monitoring and Assessment. October 53(1): 213-223.

Battelle Marine Sciences Laboratory, Pentec Environmental, Striplin Environmental Associates, Shapiro Associates, Inc., and King County Department of Natural Resources (KCDNR), 2001. Reconnaissance Assessment of the State of the Nearshore

Ecosystem: Eastern Shore of Central Puget Sound, including Vashon and Maury Islands (WRIAs 8 and 9). Prepared for KCDNR, Seattle, Washington. Available from: http://www.kingcounty.gov/environment/watersheds/central-puget-sound/nearshore-environments/reconnaissance-assessment.aspx.

BBL (Blasland, Bouck, and Lee, Inc.), 1995a. Draft Non-time Critical Removal Action Documentation Report, Volume 1. Grasse River Study Area, Massena, NY. Blasland, Bouck, and Lee, Inc. Syracuse, NY. December.

BBL, 1995b. Alternative Specific Remedial Investigation Report, Sheboygan River and Harbor, Volume 1 of 4 (Tecumseh Products Company, Sheboygan Falls, Wisconsin). Blasland, Bouck, and Lee, Inc. Syracuse, NY. October.

Beckingham, B., and U. Ghosh, 2011. Field-Scale Reduction of PCB Bioavailability with Activated Carbon Amendment to River Sediments. Environmental Science and Technology, 45(24), 10567-10574.

Borja A., Dauer D.M., Elliott M., 2010. Medium and Long-term Recovery of Estuarine and Coastal Ecosystems: Patterns, Rates and Restoration Effecttiveness. Estuarine and Coasts. Vol. 33, pp. 1249-1260. September 24, 2010.

Boskalis-Dolman, J. (Bean Environmental LLC), 2006. Personal Communication to S. Emmons (The RETEC Group, Inc.). Soil Washing Viability for Sand Fractions for the Lower Duwamish. May 7, 2006.

Bridges, T., K. Gustavson, P. Schroeder, S. Ells, D. Hayes, S. Nadeau, M. Palermo, and C. Patmont, 2010. Dredging Processes and Remedy Effectiveness: Relationship to the Four Rs of Environmental Dredging. Integrated Environmental Assessment and Management. 2010, 6, 619–630.

Brocher, T.M., T.L. Pratt, K.C. Creager, R.S. Crosson, W.P. Steele, C.S. Weaver, A.D. Frankel, A.M. Trehu, C.M. Snelson, K.C. Miller, S.H. Harder, and U.S. ten Brink, 2000. Urban Seismic Experiments Investigate Seattle Fault and Basin. In: EOS, Trans. *AGU*, v.81, pp.545, 551-552. http://earthquake.usgs.gov/regional/pacnw/hazmap/ships/eos/dryships.php

Bucknam, R.C., E. Hemphill-Haley, and E.B. Leopold, 1992. Abrupt Uplift within the Past 1700 Years at Southern Puget Sound, Washington. In: *Science*, v.258, pp. 1611-1614.

California EPA (California Environmental Protection Agency), 2005. Air Toxics Hot Spots Program Risk Assessment Guidelines, Part II Technical Support Document for Describing Available Cancer Potency Factors. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. May 2005.

Cannon, J., 2006. Adaptive Management in Superfund. In: NYU Environmental Law Review, Volume XIII, Issue #3: 561-612. 2006.

Chadwick B., Kirtay V., Rosen G., Johnston R.K., Conder J., Grover M., Webb R., Collins J., Germano J., and B. Helland, 2014. Short-term Performance of an Activated Carbon Amendment to Reduce PCB Bioavailability at an Active Naval Shipyard. Interim Report – Project ER-201131. Submitted to: Environmental Security Technology Certification Program. Submitted by: Space and Naval Warfare Systems Center Pacific Project Team. August 2014.

Cho, Y., U. Ghosh, A.J. Kennedy, A. Grossman, G. Ray, J.E. Tomaszewski, D. Smithenry, T.S. Bridges, and R.G. Luthy, 2009. Field application of activated carbon amendment for in situ stabilization of polychlorinated biphenyls in marine sediment Environ. Sci. Technol. 2009, 43, 3815– 3823.

City of Tacoma and Floyd Snider, 2007. Thea Foss and Wheeler-Osgood Waterways Remediation Project, Year 0 Baseline Monitoring Annual Operations, Maintenance, and Monitoring Report. Prepared for the U.S. Environmental Protection Agency. February 28, 2007.

Connolly J.P., J.D. Quadrini, and J.J. McShea, 2007. Overview of the 2005 Grasse River Remedial Options Pilot Study. In: Proceedings, Remediation of Contaminated Sediments—2007. Savannah, GA. Columbus (OH): Battelle.

Cornelissen, G., M.E. Krus, G.D. Breedveld, E Eek, A.M.P. Oen, H.P.H. Arp, C. Raymond, G. Samuelsson, J. E. Hedman, O. Stokland, and J.S. Gunnarsson, 2011. Remediation of Contaminated Marine Sediment Using Thin-Layer Capping with Activated Carbon—A Field Experiment in Trondheim Harbor, Norway. Environ. Sci. Technol. 2011, 45, 6110–6116.

Cornelissen, G., Gunnarsson, J., Norwegian Geotechnical Institute, Stockholm University, and U. Ghosh, 2011. Sediment Remediation Through Activated Carbon Amendment.

Long-term monitoring of a field pilot in Trondheim Harbour. Final Report. Norwegian Research Council ”Coast and Sea” Project 185032. April.

DEA (David Evans and Associates), 2010. Port of Seattle Multibeam Bathymetry Memorandum, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. June 15, 2010.

Desrosiers, R., and C. Patmont, 2009. Environmental Dredging Residuals – Case Study Summaries and Analyses. In: G.S. Durell and E.A. Foote (Conference Chairs), Remediation of Contaminated Sediments – 2009. Battelle Memorial Institute, Columbus, OH.

DMMP (Dredged Material Management Program), 2009. OSV *Bold* Summer 2008 Survey Data Report. Final. Prepared by the DMMP agencies, including U.S. Army Corps of Engineers Seattle District, U.S. Environmental Protection Agency Region 10, Washington State Department of Natural Resources, and Washington State Department of Ecology. June 25, 2009.

Ecology (Washington State Department of Ecology), 1995. Elliott Bay Waterfront Recontamination Study, Volumes I and II. Prepared for the Elliott Bay/Duwamish Restoration Program Panel. Panel Publication 10. Publication No. 95-607.

Ecology, 2001. Model Toxics Control Act Cleanup Regulation: Process for Cleanup of Hazardous Waste Sites, Chapter 173-340 WAC. Publication No. 94-06. Washington State Department of Ecology, Toxics Cleanup Program, Olympia, Washington. 2001, revised November 2007.

Ecology, 2006. Impacts of Climate Change on Washington’s Economy: A Preliminary Assessment of Risks and Opportunities. Produced by Washington Economic Steering Committee and the Climate Leadership Initiative Institute for a Sustainable Environment, University of Oregon for the Washington State Department of Ecology, and the Washington State Department of Community, Trade and Economic Development. November 2006.

Ecology, 2013. Sediment Management Standards. Chapter 173-204 Washington Administrative Code (WAC). Washington State Department of Ecology, Olympia, Washington. Publication No. 13-09-055. Revised February 2013.

Ecology, 2017. Sediment Cleanup Users Manual II. Guidance for Implementing the Cleanup Provisions of the Sediment Management Standards, Chapter 173-204 WAC. Publication No. 12-09-057. April 2017.

EERI and WMDEMD (Earthquake Engineering Research Institute and the Washington Military Department Emergency Management Division), 2005. Scenario for a Magnitude 6.7 Earthquake on the Seattle Fault. June 2005.

EPA (Environmental Protection Agency), 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. EPA/540/G-89/004. U.S. Environmental Protection Agency, Washington, D.C. 1988. October 1988.

EPA, 1989. Superfund Record of Decision: Commencement Bay, Near Shore/Tide Flats. Pierce County, WA. EPA/ROD/R10-89/020.

EPA, 1991a. Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals). U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C. EPA 540/R-92/003. December 1991.

EPA, 1991b. A Guide to Principal Threat and Low Level Threat Wastes. Superfund Publication 9380.3-06FS. U.S. Environmental Protection Agency, Washington, D.C. November 1991.

EPA, 1992. Guidance for Data Useability In Risk Assessments (Part A). PB92 - 963356. Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, DC.

EPA, 1993. Record of Decision: Declaration, Decision Summary, and Responsiveness Summary for Harbor Island Soil and Groundwater, Seattle, Washington. U.S. Environmental Protection Agency Region 10, Seattle, Washington. September 1993.

EPA, 1996. Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5. Contract Document 68-CO-0068-43. U.S. Environmental Protection Agency, Region 5. Chicago, IL.

EPA, 1997a. Clarification of the Role of Applicable or Relevant and Appropriate Requirements in Establishing Preliminary Remediation Goals under CERCLA. OSWER 9200.4-23. August 1997.

EPA, 1997b. Rules of Thumb for Superfund Remedy Selection. U.S. Environmental Protection Agency. Office of Emergency and Remedial Response, Washington, D.C. EPA 540-R-97-013. August 1997.

EPA, 1998. Guidelines for Ecological Risk Assessment. EPA/630/R-95/002 F. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, D.C. May 1998.

EPA, 1999a. A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents. EPA 540-R-98-031. U.S. Environmental Protection Agency, Washington, D.C. July 1999.

EPA, 1999b. Asian and Pacific Islander Seafood Consumption Study in King County, Washington. Exposure information obtained through a community-centered approach. Study results and education outreach. EPA 910/R-99-003. Office of Environmental Assessment, Risk Evaluation Unit, U.S. Environmental Protection Agency Region 10, Seattle, Washington. May 1999.

EPA, 2000a. A Guide to Developing and Documenting Cost Estimates during the Feasibility Study. Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. 20460. EPA 540-R-00-002 OSWER 9355.0-75. July 2000.

EPA, 2000b. Commencement Bay Nearshore/Tideflats Superfund Site – Explanation of Significant Differences. August.

EPA, 2001. Frequently Asked Questions about Atmospheric Deposition. EPA-453/R-01/009. Office of Wetlands, Oceans, and Watersheds and Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Washington, D.C. September 2001.

EPA, 2002a. Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites. Office of Solid Waste and Emergency Response. U.S. Environmental Protection Agency, Washington, D.C. OSWER Directive 9285.6-08. February 12, 2002.

EPA, 2002b. Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites. U.S. Environmental Protection Agency, Washington, D.C. EPA 540-R-01-003, OSWER 9285.7-41. September 2002.

EPA, 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. Office of Solid Waste and Emergency Response. U.S. Environmental Protection

Agency, Washington, D.C. EPA-540-R-05-012, OSWER 9355.0-85. December 2005. Available from: http://www.epa.gov/superfund/health/conmedia/sediment/guidance.htm

EPA, 2006. Administrative Settlement Agreement and Order on Consent for Supplemental Remedial Investigation/Feasibility Study, Harbor Island Superfund Site, East Waterway Operable Unit, Seattle, Washington, Port of Seattle, respondent. CERCLA Docket No. 10-2007-0030. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. October 2006.

EPA, 2007. Framework for Selecting and Using Tribal Fish and Shellfish Consumption Rates for Risk-based Decision Making at CERCLA and RCRA Cleanup Sites in Puget Sound and the Strait of Georgia. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. August 2007.

EPA, 2009a. Draft Palos Verdes Shelf Superfund Site Institutional Controls Program Implementation Plan. Prepared by the U.S. Environmental Protection Agency, Region IX. January.

EPA, 2009b. Palos Verdes Shelf Superfund Site, Operable Unit 5 of the Montrose Chemical Corp. Superfund Site Final Feasibility Study. Prepared by the U.S. Environmental Protection Agency, Region IX. May.

EPA, 2011. EPA and Ecology comments on Lower Duwamish Waterway Revised Draft Feasibility Study (submitted October 15, 2010). U.S. Environmental Protection Agency Region 10, Seattle, WA. February 25.

EPA, 2013. Use of Amendments for In Situ Remediation at Superfund Sediment Sites. OSWER Directive 9200.2-128FS. April.

EPA, 2014. Record of Decision, Lower Duwamish Waterway Superfund Site. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. November 2014.

EPA and USACE (U.S. Army Corps of Engineers), 2000. Hudson River PCBs Reassessment RI/FS Feasibility Study. U.S. Environmental Protection Agency, Region 2, and U.S. Army Corps of Engineers, Kansas City District. Website: http://www.epa.gov/hudson/study.htm.

Francingues, N.R., and M.R. Palermo, 2005. Silt curtains as a dredging project management practice. U.S. Army Engineer Research and Development Center. TN-DOER-E21.

GeoEngineers (GeoEngineers, Inc.), 1998. Terminal 30 Remedial Investigation/Feasibility Study. Final Report. Prepared for Port of Seattle.

Ghosh, U., 2010. Contaminated Sediments: New Tools and Approaches for in situ Remediation - Session II. CLU-IN Internet Seminar Sponsored by: National Institute of Environmental Health Sciences, Superfund Research Program. December 8, 2010. Presentation available at http://www.clu-in.org/conf/tio/sediments2_120810/.

Ghosh, U., R.G. Luthy, G. Cornelissen, D. Werner, and C.A. Menzie, 2011. In-situ Sorbent Amendments: A New Direction in Contaminated Sediment Management. Environ. Sci. Technol. 2011, 45, 1163–1168.

Glick, P., J. Clough, and B. Nunley, 2007. Sea-level Rise and Coastal Habitats in the Pacific Northwest. An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon. National Wildlife Foundation. June 2007. Available from: http://www.nwf.org/sealevelrise.

Goyette, D., and K.M. Brooks, 1998. Creosote Evaluation: Phase II Sooke Basin Study – Baseline to 535 Days Post Construction 1995-1996. Report prepared for Creosote Evaluation Steering Committee, Regional Program Report PR98-04. KM Brooks, Port Townsend, Washington.

Grette, G.B., and E.O. Salo, 1986. The Status of Anadromous Fishes of the Green/Duwamish River System. Prepared for the U.S. Army Corps of Engineers, Seattle District. Evans-Hamilton, Inc., Seattle, Washington.

HDR (HDR Engineering, Inc.), 1997. Alki Transfer/CSO Project East Duwamish Waterway Crossing Plan and Profile. Prepared for King County Department of Metropolitan Services.

Integral, 2015. Slip 4 Early Action Area Long-Term Monitoring Data Report – Year 3. December 24, 2015.

Janssen, E.M-L., M.N. Elecroteau, S.N. Luoma, and R.G. Luthy, 2009. Measurement and Modeling of Polychlorinated Biphenyl Bioaccumulation from Sediment for the

Marine Polychaete *Neanthes arenaceodentata* and Response to Sorbent Amendment. Environ. Sci. Technol. 2009. Volume 44, Number 8, 2857–2863.

Janssen, E.M-L., J.K. Thompson, S.N. Luoma, and R.G. Luthy, 2011. PCB-induced changes of a benthic community and expected ecosystem recovery following in situ sorbent amendment. Presentation to SedNet. Venice, Italy. April 6-9, 2011. Presentation available at http://www.sednet.org/download/Presentation8-Janssen.pdf.

Johnson, S.Y., C.J. Potter, J.M. Armentrout, J.J. Miller, C. Finn, and C.S. Weaver, 1996. The Southern Whidbey Island Fault: An Active Structure in the Puget Lowland, Washington. *GSA Bulletin*, v. 108, no. 3, pp. 334-354, 1996.

Kerwin, J., and T.S. Nelson, 2000. Habitat Limiting Factors and Reconnaissance Assessment Report, Green/Duwamish and Central Puget Sound Watersheds (WRIA 9 and Vashon Island). Washington Conservation Commission, Lacey, Washington, and King County Department of Natural Resources, Seattle, Washington.

King County, 1999. King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay. Volume 1, Appendix B2, B3, & B4: Human Health, Wildlife, and Aquatic Life Risk Assessments. King County Department of Natural Resources, Seattle, Washington.

King County, 2008. Lower Duwamish Waterway Source Control Project: Passive Atmospheric Deposition Sampling, Lower Duwamish Waterway: Monitoring report - October 2005 to April 2007. King County Department of Natural Resources and Parks, Seattle, Washington.

King County, 2010. Pier 53-55 Sediment Cap and Enhanced Natural Recovery Area Remediation Project 2002 Data and Final Report. King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. June 2010.

King County, 2013. Lower Duwamish Waterway Source Control: Bulk Atmospheric Deposition Study Draft Data Report. King County Department of Natural Resources and Parks, Seattle, Washington.

King County, 2016. Lower Duwamish Waterway Source Control: Green River Watershed Suspended Solids Data Report. Prepared by Carly Greyell and Debra Williston, Water and Land Resources Division. Seattle, Washington.

Lampert, D.J., and D. Reible, 2009. An Analytical Modeling Approach for Evaluation of Capping of Contaminated Sediments. Soil and Sediment Contamination: An International Journal, 18: 4, 470-488. Mickelson & Williston, p 5-45.

Luthy, R.G., Y-M Cho, U. Ghosh, T.S. Bridges, and A.J. Kennedy, 2009. Field Testing of Activated Carbon Mixing and In situ Stabilization of PCBs in Sediment at Hunters Point Shipyard Parcel F, San Francisco Bay, California. Environmental Security Technology Certification Program Project No. ER-0510. August 5, 2009.

Menzie, C.A., 2011a. Contaminated Sediments: New Tools and Approaches for in situ Remediation - Session III. CLU-IN Internet Seminar Sponsored by: National Institute of Environmental Health Sciences, Superfund Research Program. January 19, 2011. Presentation available at http://www.clu-in.org/conf/tio/sediments3_011911/

Menzie, C.A., 2011b. The Use of Pilot Studies for Assessing In situ Sediment Treatment with Activated Carbon. Presentation to the Sediment Management Work Group. Philadelphia, PA. October 5, 2011.

Muckleshoot Indian Tribe and Port of Seattle, 2006. Letter of Agreement between Muckleshoot Indian Tribe and Port of Seattle Regarding Slip 27 and Terminal 115. July 13.

National Assessment Synthesis Team, 2000. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. U.S. Global Change Research Program, Washington, DC.

NavFac, 1986. Design Manual DM-7.02, SN 0525-LP-300-7071. Foundations and Earth Structures. Naval Facilities Engineering Command, Alexandria, VA.

NRC (National Research Council), 2007. Sediment Dredging at Superfund Megasites – Assessing the Effectiveness. Committee on Sediment Dredging at Superfund Megasites. Board on Environmental Studies and Toxicology, Division of Life and Earth Studies. National Research Council of the National Academies. The National Academies Press, 500 5th St, NW Washington D.C., 20001.

NRC, 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press. Available at: https://doi.org/10.17226/13389.

Oates, D, 2007. Personal communication (conversation with Anchor Environmental, L.L.C. staff regarding utility locate of underwater cables as part of T-18 bulkhead construction in 2003). KPFF Consulting Engineers, Olympia, Washington.

Oen, A.M.P., and G. Cornelissen, 2010. In situ sediment remediation through activated carbon amendment: Trondheim Harbour and other field trials. Presentation at Sediment Workshop 2010 in Nepal. Kathmandu, Nepal. November 14-21, 2010.

Oen, A.M.P., E.M.L. Janssen, G. Cornelissen, G.D. Breedveld, E. Eek, and R.G. Luthy, 2011. In situ measurement of PCB pore water concentration profiles in activated carbon-amended sediment using passive samplers. Environ. Sci. Technol. 2011, 44, 4053–4059.

Olsen, C.R., Simpson, H.J., Bopp, R.F., Williams, S.C., Peng, T.H., and B.L. Deck, 1978. Geochemical Analysis of the Sediments and Sedimentation of the Hudson River Estuary. J Sed Petrol 48:401-418.

Orson, R.A., Simpson, R.L., and E.E. Good, 1990. Rates of Sediment Accumulation in a Tidal Freshwater Marsh. J Sed Petrol 19:849-869.

Palermo, M., 2009. In Situ Volume Creep for Environmental Dredging Remedies. Fifth International Conference on Remediation of Contaminated Sediments, D3. Jacksonville, Florida. February 4.

Palermo, M.R., J.E. Clausner, M.P. Rollings, G.L. Williams, T.E. Myers, T.J. Fredette, and R.E. Randall, 1998a. Guidance for Subaqueous Dredged Material Capping. Technical Report DOER-1. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. Website: http://www.wes.army.mil/el/dots/doer/pdf/doer-1.pdf.

Palermo, M.R., J. Miller, S. Maynord, and D. Reible, 1998b. Assessment and Remediation of Contaminated Sediments (ARCS) Program Guidance for In-Situ Subaqueous Capping of Contaminated Sediments. EPA 905/B-96/004. Prepared for the Great Lakes National Program Office, U.S. Environmental Protection Agency, Chicago, Illinois. Website: http://www.epa.gov/glnpo/sediment/iscmain.

Palmer, S.P., S.L. Magsino, E.L. Bilderback, J.L. Poelstra, D.S. Folger, and R.A. Niggemann, 2004. Liquefaction Susceptibility and Site Class Maps of Washington State by County. Washington Division of Geology and Earth Resources, Washington State Department of Natural Resources. http://www.dnr.wa.gov/Publications/ger_misc_tech_report_liq_sus_central_puget_sound.pdf.

Patmont, C., 2013. In Situ Sediment Immobilization Treatment: A Demonstrated Sediment Cleanup Technology. Presented at the Seventh International Conference on Remediation of Contaminated Sediments, Dallas, TX. February 7, 2013.

Patmont, C., and M. Palermo, 2007. Case Studies of Environmental Dredging Residuals and Management Implications. Paper D-066, in: Remediation of Contaminated Sediments—2007, Proceedings of the Fourth International Conference on Remediation of Contaminated Sediments. Savannah, Georgia. January.

Patmont, C., J. Davis, T. Dekker, M. Erickson, V. Magar, and M. Swindoll, 2004. Natural Recovery: Monitoring Declines In Sediment Chemical Concentrations And Biological Endpoints. Paper No. C-04 in Remediation of Contaminated Sediments - 2003: Proceedings of the Second International Conference on Remediation of Contaminated Sediments, Venice, Italy.

Poston, T., 2001. Treated Wood Issues Associated with Overhead Structures in Marine and Freshwater Environments. White Paper prepared for Washington Departments of Ecology. Prepared by Ted Poston, Battelle, Richland, Washington.

Pratt, T.L., S. Johnson, C. Potter, W. Stephenson, and C. Finn, 1997. Seismic Reflection Images beneath Puget Sound, Western Washington State: The Puget Lowland Thrust Sheet Hypothesis. In: *Journal of Geophysical Research*, Vol. 102, pp. 27469-27489.

PSCAA (Puget Sound Clean Air Agency), 2003. Final Report: Puget Sound Air Toxics Evaluation. Puget Sound Clean Air Agency, Seattle, Washington. October 2003.

QEA (Quantitative Environmental Analysis), 2008. Lower Duwamish Waterway Sediment Transport Modeling (STM) Report, Final. Prepared for USEPA, Region 10, and the Washington State Department of Ecology. Quantitative Environmental Analysis, Montvale, NJ. October.

RETEC, 2005. Lower Duwamish Waterway Remedial Investigation/Feasibility Study, Final Identification of Candidate Cleanup Technologies for the Lower Duwamish Waterway Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 10, and Washington State Department of Ecology. December 12.

Sarkar, D., Essington, M.E., and K.C. Misra, 2000. Adsorption of Mercury(II) by Kaolinite. Soil Sci. Soc. Am. J. 64:1968-1975.

Schuchardt, D., E. Pilcher, and R. Carscadden, 2012. Slip 4 Early Action Cleanup, Seattle, WA. Presented at the Dredging 2012 Conference, PIANC USA/COPRI ASCE, San Diego, CA. October 23, 2012.

Shannon, J., 2006. Personal communication (e-mails to Matt Luxon, Windward Environmental LLC, regarding Duwamish-Elliott beach seine data collected by Taylor Associates in 1998, 2000, and 2002-2003. Biologist, Taylor Associates, Seattle, Washington. March 30, 2006.

Sumeri, A., 1984. "Capped In-Water Disposal of Contaminated Dredged Material," in "Dredging and Dredged Material Disposal" (Vol 2), R.L. Montgomery and J.W. Leach, eds., Proceedings of Conference Dredging '84, American Society of Civil Engineers, Clearwater Beach, FL.

Sumeri, A., 1989. "Confined Aquatic Disposal and Capping of Contaminated Sediments in Puget Sound," Proceedings of WODCON XII; Dredging: Technology, Environmental, Mining, World Dredging Congress, Orlando, FL.

Sunchasers, 2000. Terminals 25 & 30 Bathymetric and Jet Probe Survey Report. Prepared for Port of Seattle. September 14.

Taylor Associates, 2004. Memorandum to S. McGroddy, Windward Environmental LLC, from J. Shannon regarding Duwamish/Diagonal sediment remediation project fish monitoring. June 3, 2004.

Tetra Tech Inc., 2010. Lockheed West Seattle Superfund Site. Final Screening of Remedial Technologies and Assembly of Preliminary Alternatives. Prepared for Lockheed Martin. November.

Thompson, T., G. Hartman, C. Houck, J. Lally, and R. Paulson, 2003. Methods and Considerations for Cap Design, Contracting, Construction, and Monitoring over Soft, Unconsolidated Sediments. Proceedings of the In-Situ Contaminated Sediment Capping Workshop. Cincinnati, OH, May 12-14, 2003. EPRI, Palo Alto, CA.

Titov, V., F.I. González, H.O. Mojfeld, A.J. Venturato, 2003. NOAA TIME Seattle Tsunami Mapping Project: Procedures, Data Sources, and Products. NOAA Technical Memorandum OAR PMEL-124. September 2003.

USACE (U.S. Army Corps of Engineers), 1994. Sediment Chemistry Profiles of Capped Deposits Taken 3 to 11 Years After Capping. Dredging Research Technical Notes. DRP-549. May.

USACE, 2002. Port of Seattle, Washington. Port Series No. 36. Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, Virginia.

USACE, 2008a. Technical Guidelines for Environmental Dredging of Contaminated Sediments. ERDC/EL TR-08-29. U.S. Army Corps of Engineers. September.

USACE, 2008b. The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk. Technical Report ERDC/EL TR-08-4. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://el.erdc.usace.army.mil/elpubs/pdf/trel08-4.pdf.

USACE, 2015. Approved Work Windows for Fish Protection for All Marine/Estuarine Areas, excluding the Mouth of the Columbia River (Baker Bay) by Tidal Reference Area. 28 July 2015. Accessed on: August 9, 2017. Available from: http://www.nws.usace.army.mil/Portals/27/docs/regulatory/ESA%20forms%20and%20templates/Appendix %20D %20-revised%20 Marine%20Fish%20Work%20Windows%207-28-15.pdf.

USACE, 2016. Draft Integrated Feasibility Report and Environmental Assessment, Seattle Harbor Navigation Improvement Project, Seattle, Washington. August 2016. Available from: http://www.nws.usace.army.mil/Missions/Civil-Works/Programs-and-Projects/Projects/Seattle-Harbor/. Accessed on: September 21, 2016.

USACE – DOER, 2000. Equipment and Processes for Removing Debris and Trash from Dredged Material. U.S. Army Corps of Engineers, Dredging Operations and Environmental Research Technical Notes C17. ERDC TN-DOERC17. August.

USACE, Ecology, and DNR, 1999. Puget Sound Confined Disposal Site Study Programmatic NEPA/SEPA Environmental Impact Statement. Prepared in cooperation with Striplin Environmental Associates, Anchor Environmental, Ogden Beeman Associates, ECO

Resource Group, EnviroIssues, and Marshal and Associates. U.S. Army Corps of Engineers, Washington State Department of Ecology, and Washington State Department of Natural Resources. Two volumes. October.

USGS (U.S. Geological Survey), 2016. Progress Report: Assessing Sediment and Toxic Chemical Loads from the Green River, Washington, to the Lower Duwamish Waterway. Prepared for the Washington State Department of Ecology. April 8, 2016.

Van den Berg, M., L.S. Birnbaum, M. Denison, M. De Vito, W. Farland, M. Feeley, H. Fiedler, H. Hakansson, A. Hanberg, L. Haws, M. Rose, S. Safe, V. Schrenk, C. Tohyama, A. Tritscher, J. Tuomisto, M. Tysklind, N. Walker, and R.E. Peterson, 2006. The 2005 World Health Organization Reevaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds. Toxicology Science 93(2): 223-241.

Weston, R.F., 1993. Harbor Island Remedial Investigation Report. Prepared for U.S. Environmental Protection Agency, Region 10. May 1993.

Weston and Pascoe (Weston Solutions and Pascoe Environmental Consulting), 2006. Jimmycomelately Piling Removal Monitoring Project, Final Report. Prepared for the Jamestown S'Klallam Tribe. March 2006. 109pp.

Windward (Windward Environmental LLC), 2007a. Lower Duwamish Waterway Remedial Investigation. Remedial Investigation Report, Appendix A, Baseline Ecological Risk Assessment. Prepared for Lower Duwamish Waterway Group. July 31, 2007.

Windward, 2007b. Lower Duwamish Waterway Remedial Investigation. Remedial Investigation Report, Appendix B, Baseline Human Health Risk Assessment. Prepared for Lower Duwamish Waterway Group. November 12, 2007.

Windward, 2008a. East Waterway Phase 1 Removal Action: Recontamination Monitoring 2007 Data Report. Windward Environmental, LLC, Seattle, WA.

Windward, 2008b. East Waterway Phase 1 Removal Action: Recontamination Monitoring 2008 Data Report. Windward Environmental, LLC, Seattle, WA.

Windward, 2009. Lower Duwamish Waterway Remedial Investigation. Remedial Investigation Report, Appendix B, Baseline Human Health Risk Assessment. Errata:

adjustment to Tulalip Tribes seafood consumption rates and the impact on risk estimates. Prepared for Lower Duwamish Waterway Group.

Windward, 2010a. Lower Duwamish Waterway Remedial Investigation. Remedial Investigation Report. Final. Prepared for Lower Duwamish Waterway Group. July 2010.

Windward, 2010b. Data Report: Clam Surveys and Sampling of Clam Tissue and Sediment. Final. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. January 2010.

Windward, 2010c. Data Report: Clam Survey, Geoduck Survey, Fish and Shellfish Tissue Collection PCB Congener and Dioxin/Furan Results. Final. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. July 2010.

Windward, 2010d. Data Report: Fish and Shellfish Tissue Collection. Final. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. April 2010.

Windward, 2010e. HHRA Technical Memorandum. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study.

Windward, 2011. Data Report: Subsurface Sediment. Final. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. April 2011.

Windward, 2012a. Baseline Ecological Risk Assessment (ERA). Appendix A, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. August 2012.

Windward, 2012b. Baseline Human Health Risk Assessment (HHRA). Appendix B, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. September 2012.

Windward, 2019. Addendum to Appendix B, Baseline Human Health Risk Assessment, of East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. February 2019.

Windward and Anchor QEA, 2014. Supplemental Remedial Investigation. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. January 2014.