Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

PRELIMINARY (30%) REMEDIAL DESIGN BASIS OF DESIGN REPORT FOR LOWER DUWAMISH WATERWAY UPPER REACH

For submittal to

U.S. Environmental Protection Agency
Seattle, WA

August 29, 2022

Prepared by:

ANCHOR QEA

1201 3rd Avenue • Suite 2600
Seattle, Washington • 98101

in association with

Windward environmental LLC

200 West Mercer Street • Suite 401
Seattle, Washington • 981199

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

ABBREVIATIONS

AC	activated carbon
AOC	Administrative Order on Consent
ARAR	applicable or relevant and appropriate requirements
BAZ	biological active zone
BBP	benzyl butyl phthalate
BEHP	bis(2-ethylhexyl) phthalate
BMP	best management practice
BODR	Basis of Design Report
CFR	Code of Federal Regulations
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CQAP	Construction Quality Assurance Plan
DER	Data Evaluation Report
DNR	Department of Natural Resources
EAA	early action area
Ecology	Washington State Department of Ecology
EF	exceedance factor
EFH	Essential Fish Habitat
ENR	enhanced natural recovery
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FNC	federal navigation channel
FOS	Factor of Safety
FS	feasibility study
HDPE	high-density polyethylene
HEA	Habitat Equivalency Analysis
HEC-RAS	Hydrologic Engineering Center – River Analysis System
ICIAP	Institutional Controls Implementation and Assurance Plan
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LTMMP	Long-Term Maintenance and Monitoring Plan
MHHW	mean higher high water
MLLW	mean lower low water
MNR	monitored natural recovery
MTCA	Model Toxics Control Act

N/A	not applicable
NAD83/91	North American Datum 83 through the 1991 adjustment
NMFS	National Marine Fisheries Service
NTU	Nephelometric Turbidity Unit
PAH	polycyclic aromatic hydrocarbon
pcf	pound per cubic foot
PCB	polychlorinated biphenyl
PDI	pre-design investigation
PM_{10}	particulates less than 10 microns in diameter
PSCAA	Puget Sound Clean Air Agency
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RAA	remedial action area
RAL	remedial action level
RAO	Remedial Action Objective
RAWP	Remedial Action Work Plan
RCP	Representative Concentration Pathway
RCW	Revised Code of Washington
RD	remedial design
RDWP	Remedial Design Work Plan
RI	remedial investigation
RM	river mile
RMC	residuals management cover
ROD	Record of Decision
SCO	sediment cleanup objective
SD	storm drain
SMA	Sediment Management Area
T-117	Terminal 117
TIN	triangulated irregular networks
USACE	U.S. Army Corps of Engineers
USC	United States Code
USFWS	U.S. Fish and Wildlife Service
WAC	Washington Administrative Code
WCRP	Washington Coastal Resiliency Project
WQMP	Water Quality Monitoring Plan
ZVI	zero valent iron

1 Introduction

This Preliminary (30%) Remedial Design (RD) Basis of Design Report (BODR) describes the basis of design criteria and other key elements for implementing the cleanup remedy for the upper reach of the Lower Duwamish Waterway (LDW) Superfund Site in King County, Washington. The upper reach encompasses river miles (RM) 3.0 to RM 5.0 of the LDW. This BODR has been prepared consistent with the U.S. Environmental Protection Agency (EPA)-approved Remedial Design Work Plan (RDWP) (Anchor QEA and Windward 2019a) for the upper reach and the EPA's November 2014 Record of Decision (ROD; EPA 2014) as modified by an Explanation of Significant Differences (EPA 2021). This BODR was prepared on behalf of the City of Seattle, King County, the Port of Seattle, and The Boeing Company, collectively referred to as the Lower Duwamish Waterway Group (LDWG). Contracting for implementing the upper reach remedial action will be undertaken by an entity to be determined, which is referred to as the "Implementing Entity" in this document.

1.1 Administrative Orders on Consent

In December 2000, LDWG entered into an Administrative Order on Consent (AOC) for Remedial Investigation/Feasibility Study (RI/FS) with EPA and the Washington State Department of Ecology (Ecology) to conduct an RI/FS for the LDW. In September 2001, the LDW was formally added to the National Priorities List as a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund) site; in February 2002, Ecology listed the LDW as a cleanup site under the Washington Model Toxics Control Act (MTCA). EPA and Ecology have divided lead agency responsibility for addressing the site: EPA is responsible for administering the cleanup of the sediments in the waterway, and Ecology is responsible for controlling sources of pollution to the waterway. The RI was completed in 2010 (Windward 2010) and the FS was completed in 2012 (AECOM 2012). A ROD was issued by EPA in 2014 (EPA 2014).

Five amendments to the AOC have been signed. The first three amendments cover activities that have been performed prior to the start of RD. The fourth amendment (AOC4) includes development of the RD for the upper reach, progressing from the preliminary design phase (30%) through 60%, 90%, and final (100%) designs. This document represents the basis of design as of the Preliminary (30%) RD and will be built upon in future design phases. The fifth amendment includes development of RD for the middle reach, which is on a different timeline and will be documented separately.

1.2 Data Collection and Evaluation

The Preliminary (30%) RD is supported by a design dataset that includes data collected during two phases of pre-design investigations (PDI). The design data are described and presented in the PDI Data Evaluation Report (DER; Anchor QEA and Windward 2022a). The DER presents summaries of the PDI investigations including the chemistry and geotechnical results of the Phase I and Phase II PDI. The PDI investigations were implemented in accordance with the following plans: the PDI Quality

Assurance Project Plan (QAPP; Anchor QEA and Windward 2020); the Addendum to the PDI QAPP for Phase II (Phase II QAPP Addendum) (Anchor QEA and Windward 2021a); and the Survey QAPP (Anchor QEA and Windward 2019b) and Survey QAPP Addendum (Anchor QEA and Windward 2021b).

The DER defines areas in the upper reach with exceedances of remedial action levels (RALs), lists preliminary technology assignment options for these areas, and identifies initial data gaps for the Phase III PDI. The Phase III PDI will take place during late fall 2022 and will be incorporated into the Pre-Final (90%) RD. Based on the RAL exceedance areas presented in the DER, remedial action areas (RAAs) are defined in this Preliminary (30%) RD BODR. The RAAs will be refined and grouped into sediment management areas at Intermediate (60%) RD, as discussed in the RDWP (Anchor QEA and Windward 2019a).

1.3 Purpose and Objectives

The objective of the Preliminary (30%) RD BODR is to identify and establish design criteria for major elements of construction, present the technical evaluations of the design elements, and document how they apply to the overall remedial action for the selected remedy for the upper reach of the LDW, as set forth in the ROD and AOC4. The Preliminary (30%) RD also establishes the preliminary footprint of remediation, selects the remedial approach (e.g., dredging, capping), and provides preliminary estimates of quantities, durations, and costs to complete the remedial action.

This Preliminary (30%) RD BODR includes analyses conducted to select the design approach, including a summary and detailed justification of design assumptions, restrictions, and objectives used in the design of the selected remedy as defined by the list of BODR requirements in Section 6.2 of the RDWP. A complete list of RD elements of the Preliminary (30%) RD and subsequent design deliverables is provided in Table 6-1 of the RDWP.

1.4 Report Organization

The remainder of this document is organized into the following sections:

- Section 2: Project Background, Site Conditions, and Data Sources
- Section 3: ARARs Compliance Evaluation
- Section 4: Extents of Contamination
- Section 5: Remedial Technology Assignment
- Section 6: Remedial Action Areas Development
- Section 7: Sediment Management Areas Design Considerations
- Section 8: Geotechnical Engineering Considerations
- Section 9: Structural Engineering Considerations
- Section 10: Remedial Technology Design
- Section 11: Environmental Protection During Construction

- Section 12: Site Access
- Section 13: Preliminary Construction Sequencing and Schedule
- Section 14: Quantity Calculations and Opinion of Probable Cost
- Section 15: Construction Contracting Strategy
- Section 16: Contractor Quality Control and Construction Quality Assurance
- Section 17: Work by Others
- Section 18: Phase III PDI Preliminary Data Gap Categories
- Section 19: References

The following appendices are attached to this document:

- Appendix A: LDW Upper Reach Applicable or Relevant and Appropriate Requirements
- Appendix B: Design Considerations for cPAH RAL Exceedance Areas Relative to 2014 ROD RALs
- Appendix C: Geotechnical Appendix
- Appendix D: Preliminary Drawings
- Appendix E: Specifications Outline
- Appendix F: Construction Quality Assurance Plan Summary Table
- Appendix G: Engineered Cap Chemical Isolation Design Analysis
- Appendix H: Engineered Cap Erosion Protection Evaluation
- Appendix I: Long-Term Maintenance and Monitoring Plan Outline
- Appendix J: Sediment Remedy Institutional Controls Implementation and Assurance Plan Outline
- Appendix K: Water Quality Assessment
- Appendix L: Green Remediation Evaluation and Implementation Approach
- Appendix M: Opinion of Probable Cost
- Appendix N: Emergency Response Plan Outline
- Appendix O: Work by Others

Future RD deliverables will be submitted during Intermediate (60%) or Pre-Final (90%) RD as required by AOC4 and include the following (as described in RDWP Table 6-1):

- New BODR elements, including engineer's construction project schedule estimate, engineer's capital and operation and maintenance cost estimate, and habitat area identification
- Full set of plans and specifications
- Vessel Management Plan requirements
- Construction Quality Assurance Plan (CQAP)
- Water Quality Monitoring Plan (a component of the CQAP)
- Archaeological Monitoring and Inadvertent Discovery Plan for construction
- Biological Assessment

- Clean Water Act Section 404 and Section 10 Rivers and Harbors Act of 1899 Memorandum
- Community Outreach and Communications Plan
- Compensatory Mitigation Plan (if needed)
- Permitting and Site Access Plan

2 Project Background, Site Conditions, and Data Sources

2.1 Project Background

2.1.1 Site Description

The Duwamish River originates at the confluence of the Green and Black rivers near Tukwila, Washington, and flows northwest for approximately 12 miles prior to discharging into Elliott Bay in Puget Sound. In the early years of the twentieth century, the lower 6 miles of the Duwamish River were straightened and channelized into a commercial corridor for ship traffic, officially designated as the LDW and the East and West Waterways (located along Harbor Island). The LDW Superfund Site extends 5 miles upstream from the southern tip of Harbor Island to just upstream of the Turning Basin, a federally authorized and maintained navigation feature consisting of an area where ship traffic can turn around. The LDW Superfund site has been divided into three reaches (lower, middle, and upper) that are each undergoing RD on different timelines, with the upper reach being the first reach for which RD is being performed. Although each reach is being designed separately, some design overlap at the boundaries between reaches is necessary to transition remedial actions between reaches. The upper reach of the LDW extends from Duwamish Waterway Park (RM 3.0) to the southern end of the LDW at RM 5.0 near the bridge on South 102nd Street (Figures 2-1 and 2-2). The average width of the upper reach is 540 ft.

The banks of the LDW include public and private properties that support industrial and marine activities as well as public access, utility corridors, street ends, and bridge crossings. Additional detail is provided in Section 2.3.

2.1.2 Remedy Summary

The selected remedy for the LDW is described in Section 13 of the ROD (EPA 2014). It addresses unacceptable human health risks associated with consumption of resident fish and shellfish, and with direct contact (skin contact and incidental ingestion of sediment) from net fishing, clamming, and beach play. It also addresses ecological risks to bottom-dwelling organisms (benthic invertebrates) and wildlife.

RALs are contaminant concentrations in sediment that apply to specific locations and depths on a point-by-point basis (EPA 2014). Per the ROD, RALs are used to delineate areas that require active remediation. These RALs are dependent on the location, elevation (i.e., intertidal vs. subtidal), projected potential for natural recovery (i.e., recovery category), and shoaling conditions in the federal navigation channel (FNC). RAL depth intervals are as follows:

- **Intertidal areas:** 0 to 10 cm (0 to 4 inches) and 0 to 45 cm (0 to 1.5 ft)
- **Subtidal areas:** 0 to 10 cm (0 to 4 inches) and 0 to 60 cm (0 to 2 ft)[1]

Shoal areas[2] within the FNC also have their own set of RALs. Areas with RAL exceedances were delineated in the DER (Anchor QEA and Windward 2022a) as described in Section 4 of this BODR.

The following remedial technologies were identified in the ROD:

- Dredging [3]
- Engineered sediment caps
- Partial dredge and capping
- Placing a thin layer (nominal 6 to 9 inches) of clean material in areas that meet the criteria for enhanced natural recovery (ENR)
- Applying location-specific cleanup technologies to contaminated sediment in underpier areas or areas with structural or access restrictions (e.g., in the vicinity of dolphins/pilings, bulkheads, and riprapped or engineered banks)
- Implementing monitored natural recovery (MNR):
  - **MNR Above Benthic Sediment Cleanup Objectives (SCOs):** Surface sediment contaminant concentrations are greater than benthic SCOs but below RALs
  - **MNR Below Benthic SCO:** Surface sediment contaminant concentrations are below RALs and benthic SCOs

The upper reach remedial technology assignments for each RAL exceedance area, which are based on ROD criteria, were initially presented in the DER and have been refined in Section 5 of this BODR to reflect the Preliminary (30%) RD selected technology.

Early action areas (EAAs) compose 19 acres (14% of the area) in the upper reach. These areas were identified for early cleanup actions to accelerate cleanup and reduce risks of exposure. Remedial actions at the four EAAs in the upper reach were conducted between 1999 and 2015. Post-remediation conditions of EAAs are factored into design of adjacent areas to maintain EAA remedy performance. Figure 2-3 shows the locations of the EAAs in the upper reach.

---

[1] Subtidal RALs applicable to the 0- to 60-cm depth are dependent on recovery category designation and potential vessel scour areas (see ROD Table 28).
[2] Shoal areas are locations within the FNC where the bed elevation is higher than the authorized navigation depth.
[3] The Dredging technology also includes backfilling when dredging is performed at or above defined habitat elevations

2.2 Upland Source Control Sufficiency

Remedial construction of the upper reach will be coordinated with upland source control sufficiency evaluations by Ecology. Ecology works with the LDW Source Control Workgroup[4] on source control efforts for the LDW sediment cleanup.[5] Ecology has identified 24 source control areas for the LDW as part of their source control strategy (Ecology 2016) for the LDW sediment remedy. Nine of these source control areas drain to the upper reach and are summarized in Table 2-1.

Sufficiency recommendations will be developed by Ecology for each of these areas with RAAs (although areas may be bundled in documentation). Ecology will submit the source control sufficiency evaluations to EPA for final determinations. The sufficiency evaluations are scheduled to be completed before Final (100%) RD for the upper reach. If source control is determined not to be sufficient for an RAA, the remedial action in these areas may be delayed until sources are sufficiently controlled.

---

[4] The LDW Source Control Workgroup currently consists of representatives from Ecology, King County, City of Seattle, City of Tukwila, Port of Seattle, Puget Sound Clean Air Agency, Washington State Department of Transportation, and EPA; see ROD Section 13.2.7.

[5] Information on the current status of source control efforts can be found on Ecology's website available at: https://ecology.wa.gov/Spills-Cleanup/Contamination-cleanup/Cleanup-sites/Toxic-cleanup-sites/Lower-Duwamish-Waterway/Source-control.

Table 2-1
Summary of LDW Upper Reach Source Control Areas and Upland Cleanup Sites

Ecology Source Control Area	Upland Upper Reach Cleanup Sites[1]	Upland Cleanup Site Adjacent to In-Water Area with RAL Exceedances?
East Shoreline		
RM 2.8-3.7 East: Boeing Plant 2/Jorgensen Forge EAA	Jorgensen Forge, Boeing Plant 2[2]	Yes, adjacent to EAAs Yes, adjacent to EAAs
RM 3.7-3.9 East: Boeing Isaacson/Central King County International Airport	Boeing Isaacson Thompson	Yes
RM 3.9-4.3 East: Slip 6	8801 E Marginal Way S, Container Properties[2]	Yes Yes
RM 4.3-4.9 East: Boeing Developmental Center	Boeing Developmental Center	Yes
RM 4.9 East: Norfolk Combined Sewer Overflow/Storm Drain EAA	Emerald Gateway	No
West Shoreline		
RM 2.2-3.4 West: Riverside Drive	Duwamish Waterway Park[3]	No
RM 3.4-3.8 West: T-117 EAA	South Park Marina, T-117[2]	Yes Yes, adjacent to EAAs
RM 3.8-4.2 West: Sea King Industrial Park	Precision Engineering	No
RM 4.2-4.8 West: Restoration areas	None	No

Notes:
1. Source: https://ecology.wa.gov/Spills-Cleanup/Contamination-cleanup/Cleanup-sites/Lower-Duwamish-Waterway/Source-control/Source-control-areas
2. Boeing Plant 2, Container Properties, and T-117 are EPA-led upland cleanup sites.
3. Information regarding the Duwamish Waterway Park Site is summarized from Ecology (2022). Site listed on Ecology's Confirmed and Suspected Contaminated Sites List in 2020.

EAA: early action area
RAL: remedial action level
RM: river mile
T-117: Terminal 117

The following four upland areas that are under Ecology-led upland cleanup processes are located immediately adjacent to LDW upper reach RAL exceedance areas:

- **Boeing Isaacson Thompson:** This site is located near RM 3.8E and includes the Port of Seattle shoreline "sliver property" along a deteriorating bulkhead wall. Additional coordination with the upland site owner and Ecology will occur to determine the approach for the remedy of the adjacent RAL exceedance area (Area 18), as described in Section 10.3.2.
- **8801 E Marginal Way:** This site is located at RM 3.9/4.0E and is sometimes referred to by other names, including Centerpoint Properties and PACCAR. The need for further

coordination with the upland project site will be determined during Intermediate (60%) Design.

- **Boeing Developmental Center:** This site spans the upland area from RM 4.3 to 4.9. A stormwater improvement project, including rerouting and combining some outfalls and abandoning others, is planned near the RAL exceedance areas at the south end of the site. Further information about timing and details of the rerouting will be gathered during Intermediate (60%) Design. The need for further coordination with the upland project site will be determined during Intermediate (60%) Design.
- **South Park Marina:** This site is located at RM 3.5W and includes the upland area adjacent to South Park Marina. Additional coordination with the upland site owner and Ecology will occur to determine the approach for the remedy of the adjacent RAL exceedance area (Area 13), as described in Section 8.3.7.1.

One additional upland cleanup site located adjacent to an LDW upper reach RAL exceedance area is under an EPA-led cleanup process:

- **Container Properties:** This site is located at RM 4.1E. The need for further coordination with the upland project site will be determined during Intermediate (60%) Design.

Ongoing coordination between Ecology, EPA, and LDWG (during RD) and the Implementing Entity (during contracting and remedial action) will be necessary so that the RD details (e.g., upland remedial actions adjacent to or on banks, areas targeted for active in-waterway sediment remediation, timing of sources controlled) are exchanged through routine check-ins and at critical RD milestones. The following milestones represent anticipated source control sufficiency coordination check-ins during RD based on the AOC4 schedule:

- Following Preliminary (30%) RD, when RAA boundaries, bank remediation footprints, and technology assignments are nearly complete
- Following Pre-Final (90%) RD, when remediation contracting schedules are being planned to accommodate the source control sufficiency determinations that precede remedial construction

These milestones may be modified at the direction of EPA. In addition to these milestones, the LDWG design team will coordinate as needed with upland site cleanup technical teams, with the goal of optimizing design compatibility and sequencing of the LDW remedial action and upland actions.

Ecology is currently working on its source control sufficiency evaluation for the upper reach and is tentatively planning to submit it to EPA in January 2023. The design team is requesting a copy of Ecology's evaluation when it is submitted to EPA. This will assist in discussions with EPA regarding any potential modifications to sequencing related to source control sufficiency.

2.3 Site Conditions

The RDWP (Section 2) provides a review of existing information and site conditions. In addition, comprehensive descriptions of the LDW environmental and physical site characteristics are presented in the *Lower Duwamish Waterway Remedial Investigation Report* (Windward 2010), *Final Feasibility Study, Lower Duwamish Waterway* (AECOM 2012), the ROD (EPA 2014), and the RDWP (Anchor QEA and Windward 2019a). Key site characteristics affecting RD are summarized in the following sections.

2.3.1 Tidal Elevations and Water Depth

The upper reach consists of 132 acres of intertidal and subtidal areas below mean higher high water (MHHW), which is 11.3 ft mean lower low water (MLLW) in the LDW; this is the landward boundary for sediment remedial action per the ROD. Approximately 55 acres of the upper reach are considered intertidal, with bed elevations between +11.3 ft MLLW, equivalent to MHHW, and -4 ft MLLW. Approximately 76 acres of the upper reach are considered subtidal, with bed elevations below -4 ft MLLW.

Based on National Oceanic and Atmospheric Administration annual prediction tide tables at the Eighth Avenue South tidal gauge (Station ID: 9447029), the predicted water surface elevation for 2024 at the site ranges from -3.35 ft MLLW to +12.68 ft MLLW, with an average of +6.50 ft MLLW (Table 2-2).

Table 2-2
LDW Predicted Tidal Data for 2020-2024

Year	Predicted Tide Elevations (ft MLLW)		
	Mean	Minimum	Maximum
2020	+6.50	-3.79	+12.68
2021	+6.48	-4.07	+12.71
2022	+6.46	-3.21	+12.55
2023	+6.45	-3.23	+12.56
2024	+6.50	-3.35	+12.68

Notes:
Source: https://tidesandcurrents.noaa.gov/noaatideannual.html?id=9447029
ft: foot
MLLW: mean lower low water

2.3.2 Federal Navigation Channel

The upper reach includes the Turning Basin (RM 4.6 to RM 4.7) and the FNC, both of which are maintained[6] by the U.S. Army Corps of Engineers (USACE) (Figure 2-3). In this reach, the authorized

[6] Recent maintenance dredging performed by USACE has been limited to areas in the FNC south of RM 4.0.

FNC width is 150 ft and the authorized depth is -15 ft MLLW. The FNC covers 32 acres of the 76-acre subtidal area of the upper reach.

2.3.3 Infrastructure

Infrastructure within the upper reach, shown in Figure 2-3, includes waterfront facility berthing, overwater structures (e.g., piers, docks, floats, bulkheads, flow diversion structures, covered boat slips), piling (e.g., erosion control structures, fendering, mooring piles), bridges, and utilities (e.g., underwater cables and pipe structures, overwater cables, storm drains, outfalls).

2.3.4 Waterway Usage

Waterway uses are summarized in RDWP Section 2.5 and include the following:

- **Tribal use and treaty rights.** Tribal consultation will occur during the design and prior to construction at a schedule determined by EPA and could include topics such as commercial netfishing, shoreline use, access points, cultural activities, or other tribal interests.
- **Beach play and tribal clamming.** Beach play and tribal clamming were considered in the RI/FS/ROD process in the development of cleanup levels and RALs.
- **Public shoreline access**. Potential public shoreline access locations are important to consider during RD in order to maintain public safety and to reduce the impacts of construction on the public.
- **Waterway-dependent users.** Waterway-dependent users include waterfront property owners and their tenants that are supported by bank infrastructure (e.g., docks, piers, wharves, berthing areas); operators of commercial tug, barge, and cargo vessels; and recreational users.
- **Federal navigation channel.** The FNC supports water-dependent industry along the LDW. The Preliminary (30%) RD applies appropriate buffers as defined in the ROD to support USACE's ability to maintain the FNC.

2.3.5 Upland Land Use

The upper reach includes upland property in the cities of Seattle and Tukwila and unincorporated King County. The uplands surrounding the LDW upper reach are mixed industrial, commercial, residential, and some park/open space. RD considers restrictions appropriate to residential land uses (e.g., noise restrictions during construction). Upland properties are owned by a variety of landowners (Figure 2-3).

2.3.6 Early Action Areas

Four EAAs are located within the upper reach (Norfolk EAA, Boeing Plant 2 EAA, Jorgensen Forge EAA, and Terminal 117 [T-117] EAA). The RDWP summarizes the cleanup of each EAA. Existing conditions for the EAAs inform the cleanup approach in adjacent areas in this BODR as described in Section 6.1.

2.3.7 Enhanced Natural Recovery/Activated Carbon Pilot Plots

In 2015 to 2020, LDWG implemented a pilot study to assess whether the performance of ENR material amended with activated carbon (AC) was more effective than ENR alone in reducing the bioavailability of polychlorinated biphenyls (PCBs) in contaminated sediments in the LDW. Results of the study are available in the Year 3 monitoring report (Wood et al. 2021). One of the three plots, the intertidal plot, is within the upper reach at RM 3.9E.

2.3.8 Hydrodynamics and Sediment Transport

The upper reach is an estuarine environment, with freshwater entering from the Green/Duwamish River system and saltwater originating from Puget Sound. The location of the upstream interface between freshwater and marine layer flows, referred to as the saltwater wedge, is variable within the upper reach depending upon both river flow and tidal stage. During times of high river flow and low tide stages, the saltwater wedge does not enter the upper reach, whereas during low-flow conditions and high tide stages, the saltwater wedge can extend upstream of the upper reach. The upstream-most location or "toe" of the saltwater wedge is typically located between Slip 4 (RM 2.8) and the Turning Basin (RM 4.7).

The Howard Hanson Dam at the head of the Green River is managed to perform flood control during storm events. As a result, the dam limits the maximum flows within the LDW. High-flow events considered in design incorporate the effects of Howard Hanson Dam management.

Studies of sediment loads entering the LDW indicate that the LDW is net-depositional, with the vast majority of sediments entering and settling in the LDW originating from the upstream Green River catchment. The Turning Basin within the upper reach acts as a trap for suspended solids entering the LDW. Coarser grain-sized suspended solids (i.e., sands) tend to deposit in the Turning Basin, and fine-grained sediments tend to be transported and deposited farther downstream or pass through the site.

The hydrodynamics and sediment transport of the LDW (summarized in RI Section 2.6 and FS Section 2.1.3) were modeled during development of the sediment transport model. Additional detail on the hydrodynamics of the LDW is available in a recent University of Washington study (McKeon et al. 2021) and upstream transport studied by the U.S. Geological Survey (Senter et al. 2018).

2.3.9 Erosive Forces

Erosive forces within the LDW upper reach affect the stability of bed sediment or placed materials, such as capping materials. These erosive forces are generated from naturally occurring and human-induced forces. Natural forces that occur in the LDW include wind-generated waves and hydrodynamic flows (i.e., current velocities). Human-induced forces include propeller wash (prop wash) and vessel wakes in the upper reach. Potential effects of erosive forces on capping areas are discussed in Section 10.3.3.

2.3.10 Presence of Debris

Debris is common in industrial waterways such as the LDW, deposited over decades of waterway use. Submerged and emergent debris is considered in the application of remedial technologies, including the type of remedial equipment used. Specifications for management of debris will be determined during Intermediate (60%) RD. Debris identified during the PDI is shown in DER Maps 2-6a through 2-6f (Anchor QEA and Windward 2022a).

2.3.11 Existing Habitat Conditions

Habitat for aquatic species and aquatic-dependent species exists in the LDW and extends from the upper elevation of the site at MHHW (+11.3 ft MLLW) down to the deep subtidal areas of the LDW. These areas are all considered habitat and are divided into the following habitat types based on elevation:

- Deep subtidal: deeper than -10 ft MLLW
- Shallow subtidal: -10 ft MLLW to -4 ft MLLW
- Intertidal: -4 ft MLLW to +4 ft MLLW
- Upper intertidal: +4 ft MLLW to +11.3 ft MLLW

These existing habitat types are shown in Figure 2-4a along with ROD-defined "habitat areas." The ROD defines "habitat areas" as all areas with elevations above -10 ft MLLW to provide design requirements for remedial activities that occur within those elevations. The upper elevation of the ROD-defined "habitat areas" is assumed to be the MHHW elevation of +11.3 ft MLLW, since that is the upper elevation of the site per the ROD. Figure 2-4b includes potential clamming areas, existing bank conditions, bank vegetation conditions, and existing habitat restoration projects to provide context for the habitat types.

Bank habitat data collection occurred as part of the PDI Phases I and II in 2020 and 2021. As part of this data collection effort, vegetation conditions along the riverbank in the entire upper reach were documented via visual inspection. Vegetation was documented along riverbank stations including vegetation type, percent cover, and plant communities. Conditions were documented for top of bank, mid-bank, and toe of slope. The results of the vegetation observations are shown in Figure 2-4 as existing bank vegetation. Overall, the bank vegetation consists of a mix of native trees, landscaping trees, native shrubs, and non-native shrubs. Banks were also observed to document condition, including where banks are armored (i.e., engineered surface armoring) or unarmored (i.e., discontinuous armoring, poorly placed/maintained armoring, or vegetated) or bulkheaded. As shown in Figure 2-4b, approximately 41% of the upper reach bank areas are armored, 46% are unarmored, and 13% are bulkheaded.

Additionally, RI Section 2.8 and FS Section 2.1.5 summarize the habitat types in the entire LDW. The natural habitat types in the LDW include intertidal marshes, intertidal mudflats, and subtidal areas. Intertidal marshes contain marsh soils (generally fine-textured and nutrient-rich), supporting grasses, sedges, rushes, and various other plants. For example, the Hamm Creek and Turning Basin restoration areas contain intertidal marshes within the upper reach.

Intertidal mudflats are generally defined as the gently sloping areas from MLLW up to the edge of intertidal marsh vegetation (Blomberg et al. 1988). They are unvegetated, with sand or mud substrate, and represent most of the intertidal area within the upper reach.

Approximately 48 acres of the upper reach were identified in the ROD as potential clamming areas based on bathymetric elevations (i.e., shallower than -4 ft MLLW), substrate, and salinity conditions. Potential clamming areas are a subset of the intertidal areas.

Existing habitat restoration projects that have been constructed (or are currently planned for construction) within the upper reach include the following:

- King County shoreline habitat restoration project between RM 3.3W and RM 3.4W, which includes restoration of 300 linear ft of upland and intertidal habitat.
- The Boeing Plant 2 South Site habitat project between RM 3.3E and RM 3.6E, which includes 1.2 acres of restored marsh habitat, 0.95 acre of restored riparian habitat, and 0.69 acre of restored intertidal habitat.
- Duwamish River People's Park habitat restoration and shoreline access project between RM 3.5W and RM 3.9W (formerly T-117), which is restoring 14 acres of native riparian buffer, intertidal marsh, intertidal shoreline, and subtidal habitat.
- The Hamm Creek habitat area located at RM 4.3W, where 1 acre of emergent salt marsh, 2 acres of freshwater wetlands, and nearly 2,000 ft of the Hamm Creek streambed have been restored.
- The Muckleshoot Tribe habitat area at Kenco Marine, which is located near the Turning Basin at RM 4.6W where 0.43 acre of emergent marsh and intertidal habitat and 0.23 acre of riparian habitat have been restored.
- Multiple restoration projects within the Turning Basin (RM 4.7W) that have included derelict vessel removal, fill removal, creosote-treated piling and derelict structure removal, fill and large woody debris placement, and riparian and emergent plantings, resulting in 5 acres of restored intertidal habitat from 1996 through 2007 (Seaport Planning Group 2009).

2.4 Basemap Development

A basemap of the upper reach has been prepared as part of the design process and serves as the basis for the Preliminary Drawings. The basemap includes information from bathymetric and topographic surveys, structures and debris surveys, utility reviews/surveys, and review of other information.

2.4.1 Bathymetric and Topographic Surveys

Bathymetric and topographic surveys were conducted as part of the PDI and are described in detail in the DER. The horizontal datum for the basemap is North American Datum 83 through the 1991 adjustment (NAD83/91), State Plane Coordinate System, Washington North Zone, measured in U.S. Survey Feet. The vertical datum for the basemap is in feet MLLW.

In summary, bathymetric surveying was used to collect data throughout the upper reach, and topographic surveying was used to supplement the bathymetry data on bank areas within or adjacent to RAL exceedance areas up to MHHW.

Where the bathymetric and topographic survey coverage overlapped, the bathymetry data generally trumped due to data density. In cases where a gap existed between the two surveys, the gap was filled in one of two ways. For data gap areas that were surrounded by survey data that matched well on either side, the gap was filled through interpolation. For larger gaps or areas that were not surrounded by representative data, the Puget Sound LiDAR Consortium data from 2016 were used to fill gaps (PSLC 2016). Figures 2-5a through 2-5f show how the data were merged to create a composite elevation dataset for the basemap.

2.4.2 Structure and Debris Surveys

Location data and information on structures was obtained from the Waterway User Survey (Integral et al. 2018). The topographic survey team also collected survey point data for significant bank features, such as structure corner points, debris areas, and outfalls. These features have also been integrated into the basemap.

2.4.3 Utilities

Location data and information on outfalls were originally obtained from the LDW Remedial Investigation (Windward 2010), and Ecology's 2014 outfall inventory (Leidos 2014) and further updated based on Ecology's 2020 Outfall Inventory Updates for the LDW (Leidos 2020). In addition, outfall information has been supplemented by information available from the LDWG parties. As noted previously, outfall information was also collected during the topographic surveying activities when outfalls were encountered by the surveyor. Outfall information collected during the topographic survey was used to update or replace the information available from the Outfall Inventory Updates. In addition, a review of available documents, such as as-builts from recent construction projects in or near the site, was also completed. The updated outfall information is presented in the figures in this report.

In addition to outfalls, there are two known utility crossings in the upper reach (associated with the former and current South Park Bridge). The location of these crossings was incorporated into the basemap from the South Park Bridge construction documents provided by King County (King County Department of Transportation, 2010). During the Phase II PDI, LDWG conducted utility locate research and utility clearance through 811. Through this review, no additional crossings were identified.

2.4.4 Other Basemap Data

A variety of other data have been incorporated into the basemap, including the following:

- Aerial photography
- Property boundary maps
- Construction project as-built surveys (including EAAs, habitat projects, ENR/AC pilot plot boundaries)
- USACE centerline and stationing
- Habitat features along bank areas

2.5 Data Sources and Evaluations

PDI data were collected over two phases between 2019 and 2021, as summarized in the DER (Anchor QEA and Windward 2022a). The DER evaluations, which incorporated the PDI data into the design dataset, are a key input to this BODR and include the following:

- Combining new and existing sediment chemistry data based on the data management rules presented in the DER
- Comparing sediment chemistry data to the RALs based on the ROD criteria
- Adjusting recovery category areas based on ROD criteria
- Interpolating sediment chemistry data to delineate RAL exceedance areas
- Assigning preliminary remedial technologies based on ROD criteria

The methods used to define remediation areas are presented in Sections 4 through 6 of this BODR. Section 4 describes how the horizontal and vertical extents of contamination are defined. Section 5 presents the updated Preliminary (30%) RD assignment of remedial technologies. Section 6 builds on the considerations presented in Sections 4 and 5 and, combined with engineering considerations, develops and presents RAAs. Section 7 describes additional considerations that will be further developed during Intermediate (60%) RD for grouping RAAs.

The DER also summarizes the following PDI data that support the RD:

- Geotechnical investigations
- Bank visual inspections
- Structures inspections
- Bathymetric, topographic, and other surveys
- Other engineering design data

These data are used in Section 8 (Geotechnical Engineering Considerations), Section 9 (Structural Engineering Considerations), Section 10 (Remedial Technology Design Criteria), and, as supporting information, across other sections of this document.

3 ARARs Compliance Evaluation

This section describes the applicable or relevant and appropriate requirements (ARARs) embodied in the federal and state laws that govern the work, as identified in the ROD. Some of the ARARs include requirements to obtain permits and approvals. Pursuant to Section 121 of CERCLA (United States Code [USC] Title 42, Section 9621), no permits are required for on-site remedial actions. Only substantive requirements of these laws and implementing regulations apply. EPA will determine substantive compliance with ARARs in coordination with resource agencies, as EPA deems appropriate, using the supporting information presented in this section and related appendices.

ARARs fall into several categories including cleanup and waste management standards, water quality and waterway protection, environmental protection, air quality and noise, and archaeological, cultural, and historic resources. This section describes how compliance with ARARs will be achieved and documented. In general, ARAR compliance will be documented in the project specifications. However, some ARARs will require the preparation of specific deliverables as noted in the sections below. Appendix A contains supplemental details for each of the laws and regulations described herein.

3.1 Hazardous Substance Cleanup and Sediment Quality

The MTCA is Washington's environmental cleanup law (Revised Code of Washington [RCW] 70.105D, Washington Administrative Code [WAC] 173-340 and RCW 70.105D, WAC 173-204). Specific cleanup levels and RALs are identified in ROD Sections 8.2.1 and 13.2.1, respectively, in consideration of MTCA and Sediment Management Standards with the RALs used to delineate areas where remedial action is necessary. Implementing remedial actions (e.g., dredging, capping, ENR) will address the ARARs associated with cleanup standards, including MTCA Sediment Management Standards. Successful implementation of the remedy will be documented in a construction completion report and long-term monitoring will be developed as part of the Long-Term Management and Monitoring Plan. Long-term monitoring will be completed following construction and will document natural recovery and continued effectiveness of the remedy.

3.2 Surface Water Quality

Several federal and state programs regulate surface water quality, including the following:

- Ambient Water Quality Criteria per Clean Water Act (Section 304(a), 33 USC Section 1314(a))
- National Toxics Rule Standards (40 Code of Federal Regulations [CFR] 131.36(b)(1)) as applied to Washington (40 CFR 131.36(d)(14))
- Washington State Water Pollution Control Act (RCW 90.48)
- Washington State Water Quality Standards (WAC 173-201A); Aquatic Life Criteria numerical criteria (WAC 173-201A-240)

Sediment remediation will improve surface water quality in combination with source control implementation under state-lead authority. According to the ROD, surface water concentrations shall be at least as stringent as all of the following:

- All water quality standards in WAC 173-201A;
- Ambient Water Quality Criteria unless it can be demonstrated that such criteria are not relevant and appropriate for the LDW or for a specific hazardous substance; and
- The National Toxics Rule.

Monitoring for relevant Ambient Water Quality Criteria will occur during construction. Clean Water Act Section 304(a) water quality criteria are non-binding recommendations developed by EPA.

For any construction-related discharges to the LDW, water quality monitoring will occur per an approved Clean Water Act Section 401 Water Quality Monitoring Plan, and best management practices (BMPs) will be employed, as needed, for the protection of water quality.

The water quality standards for surface water implement portions of the federal Clean Water Act by specifying the designated uses for water in Washington. For the Duwamish River, designated uses include aquatic life uses for rearing and migration, recreation uses for primary contact, and water supply uses for all uses except domestic water.

3.3 Waste Management

Several federal and state laws regulate the characterization, storage, and transportation for disposal of waste materials derived from remediation activities. These include the following regulations pertaining to solid waste disposal; waste treatment, storage, and disposal; and land disposal of waste:

- Solid Waste Disposal Act (42 USC 6901-6992K; 40 CFR 257-258)
- Solid Waste Management (RCW 70.95; WAC 173-350)
- Resource Conservation and Recovery Act, Hazardous Waste (42 USC 6901-6992K, 40 CFR 260-279)
- Dangerous Waste Management (RCW 70.105; WAC 173-303-140, 141)
- Toxic Substances Control Act (15 USC 2605; 40 CFR 761.61(c))
- Resource Conservation and Recovery Act, Land Disposal Restrictions (42 USC 6901-6992K; 40 CFR 268)

All material removed from the upper reach will be managed in a commercial permitted disposal site. Based on the RI (Windward 2010) and DER (Anchor QEA and Windward 2022a), hazardous/dangerous waste has not been documented in upper reach sediments. Sediments in the upper reach are also not expected to contain concentrations of PCB compounds regulated under the Toxic Substances Control Act.

Characterization of wastes for disposal acceptance will be based on data from the RD and supplemented as needed during the remedial action. The specific disposal facility and modes of transportation will be proposed by the remedial action contractor, subject to EPA review and approval. All off-site disposal or recycling of remediation wastes will be at permitted facilities in compliance with EPA's Off-Site Rule.

When material is staged or transferred between modes of transportation, the transfer will be performed at an existing permitted commercial transfer facility, or a new transfer facility will be established with appropriate permitting or substantive permitting compliance. A transportation and disposal plan will be prepared after a remedial action contractor is selected as a pre-construction submittal as part of the contractor's remedial action workplan and reviewed by EPA.

Shipments of material from the site for disposal will be documented and quantities reconciled to confirm that material removed from the site is disposed of properly. For material that is not regulated as hazardous/dangerous waste, trip tickets will be reconciled with waste receipts issued by the disposal facility. If any material is found to be regulated as hazardous/dangerous waste, manifests will be used to track the material from the point of generation to disposal. The transportation and disposal plan will contain additional details about the characterization, handling, and documentation of material removed from the site. Quantities of waste removed from the site will be reported during construction and summarized in the construction completion report.

If characterization of sediment determines that any of the removed material will be regulated as hazardous/dangerous waste, the contractor will obtain a generator identification number and manage the material characterized as hazardous/dangerous waste in a facility permitted to manage such material. The material would be treated prior to disposal to meet the requirements of applicable land disposal restrictions. Any hazardous/dangerous waste removed from the upper reach will be managed at facilities operating in conformance with their operating permits; facility compliance will be confirmed with the appropriate EPA Off-Site Rule Contact prior to shipping any waste from the site. The episodic generation provisions of 40 CFR 262 Subpart L and WAC 173-303-173 will apply to the remedial action for any sediment found to be regulated as hazardous or dangerous waste.

3.4 Dredge/Fill and Other In-Water Construction Work

Several federal and state programs regulate the discharge of dredged and fill materials and in-water construction work. These programs include the following:

- Clean Water Act Sections 401 and 404 (33 USC 1341, 1344; 40 CFR 121.2, 230, 232; 33 CFR 320, 322-323, 328-330)
- Hydraulic Code Rules (RCW 77.65; WAC 220-110)
- Dredged Material Management Program Suitability Determination (RCW 79.105.500; WAC 332-30-166 (3))

- Rivers and Harbors Act Section 10 (33 USC 403)

Section 401 requires that a Water Quality Certification be issued by the state and that cleanup actions meet applicable water quality standards. At Pre-Final (90%) RD, evaluations to predict potential water quality impacts due to dredging will be completed. This will evaluate whether sediment resuspension during dredging or dredge return water release from haul barges is predicted to exceed water quality criteria. EPA and Ecology will use this information to develop specific water quality monitoring requirements in EPA's Section 401 Water Quality Certification. Prior to construction, EPA will issue a finding that substantive requirements of the Section 401 Water Quality Certification have been met, potentially with conditions determined in coordination with Ecology. The Water Quality Monitoring Plan that will be developed during design as part of the CQAP will describe the specific requirements for monitoring water quality during construction and steps to be taken to mitigate exceedances of water quality standards, if any occur. The Water Quality Monitoring Plan will be finalized to reflect any conditions or requirements contained in EPA's Section 401 certification compliance process. The results of water quality monitoring and any corrective actions taken will be regularly reviewed during construction to assess the need for any corrective actions and summarized in the construction completion report.

A key element of compliance with Section 404 is evaluation of the placement of dredged or fill material within waters of the U.S. Federal regulations (40 CFR 230) set forth specific standards to implement Clean Water Act Section 404(b)(1). No material will be placed in the water until EPA has reviewed and approved the characterization results. A separate 404(b)(1) Compliance Memorandum will be prepared to demonstrate compliance with Section 404(b)(1) criteria.

While a Washington Department of Fish and Wildlife Hydraulic Project Approval is not required for this project, substantive compliance will require the implementation of conditions to avoid or reduce potential impacts to aquatic species or habitats during construction. Examples of these conditions include the following:

- Work within established in-water work windows for the waterbody.
- Establish a staging area in a location that will prevent contaminants from entering waters of the state.
- Clearly mark boundaries establishing limits of work.
- Check equipment daily for leaks and completing repairs before using equipment in or near the water.
- During excavation, complete each pass with the clamshell or dragline bucket.
- Do not stockpile dredged material waterward of the ordinary high water line.
- Dispose of dredged bed materials in an approved disposal site.
- To reduce turbidity, hopper dredges, scows, and barges used to transport dredged materials to the disposal or transfer sites must completely contain the dredged material.

The Intermediate (60%) RD specifications will identify conditions to be required.

This Preliminary (30%) RD does not anticipate open-water disposal or beneficial reuse of sediments; the potential for beneficial reuse will be further evaluated in Intermediate (60%) RD as discussed further in Section 10.5.2. Therefore, there are no specific requirements of the Dredged Material Management Program that are currently incorporated into the design.

Requirements for dredging/capping elevations have been established in the ROD and were designed to preserve navigation and commerce by maintaining elevations below the authorized depth in the FNC and associated buffers, as required by the ROD. Any existing structures that are modified as part of the project will be restored to provide the functional equivalent of existing conditions.

3.5 Fisheries, Wildlife, and Endangered Species

Several regulations relate to fisheries, wildlife, and endangered species, including the following:

- Endangered Species Act (16 USC 1531-1544)
- Migratory Bird Treaty Act (16 USC 703-712; 50 CFR 10 and 21)
- Bald and Golden Eagle Protection Act (16 USC 668, 50 CFR 22)
- Bald Eagle Protection Rules (RCW 77.12.655; WAC 232-12-292)

In accordance with Section 7 of the Endangered Species Act (16 USC 1536), a Biological Assessment will be prepared for EPA to submit to the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) to initiate consultation about the potential effects of the proposed remedial action and ways to reduce those effects on species listed under the Endangered Species Act. The impact of remedial activities on all habitat types, including the ROD-defined "habitat areas", will be evaluated during Intermediate (60%) RD and Pre-Final (90%) RD to comply with Section 404 of the Clean Water Act and Section 7 of the Endangered Species Act. The result of the habitat evaluation will determine if the remedial activities are expected to improve or degrade habitat conditions relative to existing conditions.

NMFS and USFWS will typically issue a Biological Opinion that states whether EPA has ensured that its action is not likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of critical habitat. Biological Opinions provide an exemption for the "incidental take" of listed species (e.g., harassment, harm, pursuit, hunting, shooting, wounding, killing, trapping, capturing, or collecting) while specifying the extent of incidental take allowed, the reasonable and prudent measures that would reduce impacts from the federal action, and the terms and conditions with which EPA must comply.

Consideration of the effects of federal actions on Essential Fish Habitat for covered species including salmonids is required under the Magnuson-Stevens Fishery Conservation and Management Act (16 USC 1801) and its implementing regulations. Typically, state or federal agencies planning actions that might adversely affect an Essential Fish Habitat -managed species must formally consult with NMFS regarding the action. An Essential Fish Habitat evaluation will be included in the Biological Assessment.

Based on the ROD and RDWP, allowable periods of in-water work have been identified (Section 13 of this BODR) and specific habitat mitigation measures, including the use of specific substrates, and restoring optimal grades and elevations for biological resources, will be incorporated into the RD. The Biological Opinion may include additional conservation measures (such as restrictions on allowable work periods in certain areas) to further reduce impacts.

During the remedial action, steps will be taken as needed to protect habitat for migratory birds and avoid disturbances of their nests and eggs. Migratory Bird Treaty Act species will be addressed in the Section 404(b)(1) Compliance Memorandum.

If the nearest documented bald eagle nest is within the buffer distances to the remedial construction activity, construction will occur outside the bald eagle nesting season. If the nearest documented bald eagle nest is farther away from the project site than the buffer distances, the proposed action will be considered to be compliant with the Bald and Golden Eagle Protection Act. Information from the Washington Department of Fish and Wildlife bald eagle database will be obtained prior to construction to determine whether any bald habitats (e.g., nests, roosts, and forage) are present in the vicinity of the upper reach.

3.6 Floodplain Protection

In order to comply with the Floodplain Management Procedures (40 CFR 6, Appendix A, Section 6, see also Executive Order 11988), RD will avoid adversely impacting floodplains and wetlands wherever possible and consider flood hazards and floodplain management. If there is no practicable alternative to locating in or affecting floodplains or wetlands, potential impacts will be reduced to the extent practicable. In accordance with this regulation, the design will maintain the flood carrying capacity within the LDW. Section 10.7 describes the Flood Rise Analysis that was considered as part of Preliminary (30%) RD.

3.7 Shoreline Management

The City of Seattle Shoreline Master Program (Seattle Municipal Code 23.60A) and King County Shoreline Master Program (King County Code 21A.25) govern the shoreline areas within 200 ft of the ordinary high water mark. Compliance as may be necessary will be evaluated during RD. However, the Shoreline Management Act (RCW 90.58; WAC 173-26) provides exceptions for cleanup actions. Per RCW 90.58.355 and WAC 173-27-044, remedial actions at a facility pursuant to a consent decree, order, or agreed order are not required to obtain shoreline permits or undergo local review.

3.8 Air Emissions and Noise

The following federal and state laws regulate the impacts of air emissions:

- Clean Air Act (42 USC 7401-7671q; 40 CFR 50)
- Washington Clean Air Act (RCW 70.94; WAC 173-400)
- Nose Control Act (RCW 70.107; WAC 173-60-040, 050)

For the remedial action, reasonable precautions must be taken to (1) prevent the release of air contaminants, (2) prevent fugitive dust from becoming airborne, and (3) maintain and operate the source to limit emissions (RCW 70.94). The design documents (i.e., specifications) will require that the contractor's operations limit air emissions. The project will comply with these ARARs through the development of the design specifications and BMPs implemented during construction.

Maximum permissible environmental noise levels, subject to exemptions, are specified in the Noise Control Act as described in the ROD. Time of day considerations are also included.

3.9 Historic Resources

- National Historic Preservation Act Section 106 (16 USC 470; 36 CFR 800)
- Native American Graves Protection and Repatriation Act (25 USC 3001 et seq.)
- American Indian Religious Freedom Act (42 USC 1196 et seq.)

The effect of the remedial activity on any district, site, building, structure, or object included or eligible for inclusion in the National Register of Historic Places will be evaluated in consultation with the State Historic Preservation Office during RD. An Archaeological Monitoring and Inadvertent Discovery Plan will be prepared during Pre-Final (90%) RD to be implemented by the Implementing Entity or contractor during construction.

It is possible that disturbance of Native American materials from earlier times may occur as a result of sediment dredging. To protect Native American burials and cultural items, the regulations require that if such items are inadvertently discovered during excavation, the excavation must cease, and the affiliated tribes must be notified and consulted. The design documents (i.e., specifications) will require the contractor to cease excavation should such items be observed in the materials being loaded onto the barges.

If Native American or other cultural materials are unearthed as part of the remedial actions, the National Historic Preservation Act (16 USC 470), American Indian Religious Freedom Act (42 USC 1196 et seq.), and their implementing regulations require that federal agencies consider the possible effects on historic sites. If an agency finds a potential adverse effect on historic sites or structures, the agency must evaluate alternatives to "avoid, minimize, or mitigate" the impact, in consultation with the State Historic Preservation Officer. The design documents (i.e., specifications) will also require the contractor to cease excavation should such materials be observed in the materials being removed.

4 Extents of Contamination

The predicted horizontal and vertical extents of contamination defined based on the design dataset, reflect the spatial extent of sediment that exceeds RALs and represents the minimum remediation surface. This section describes the methods used to develop the horizontal and vertical extents of contamination for the site.

4.1 Horizontal Extents of Contamination

The horizontal extent of contamination was defined using the design dataset and applying geostatistical interpolation methods, as described in the DER. This delineates the areas with RAL exceedances in the upper reach. The horizontal extents of contamination adjacent to banks were extrapolated to the LDW Superfund Site boundary (i.e., MHHW elevation). Appendix K in the DER (Anchor QEA and Windward 2022a) provides a detailed analysis of the geostatistical interpolation methods and the RAL exceedance area maps.

4.1.1 Horizontal Interpolation Methods

PCBs were selected as the primary contaminant of concern (COC) for geostatistical interpolation because PCBs delineate a majority[7] of the RAL exceedance areas in the upper reach. Other COCs exceeding RALs in localized areas were evaluated separately. Interpolations were performed on two sediment depth-defined datasets over which RALs are applied: surface sediment, defined as 0 to 10 cm (0 to 4 inches); and subsurface sediment, defined as 0 to 45 cm (0 to 1.5 ft) in intertidal areas, 0 to 60 cm (0 to 2 ft) in subtidal areas, and shoaling intervals in the FNC.[8] The interpolated results for PCBs and other COCs, in surface and subsurface sediments, were combined in the final RAL exceedance area footprint, which served as the foundation for Preliminary (30%) RD to establish the horizontal extents of contamination.

Interpolation method selection and application were developed through a series of technical meetings with LDWG and EPA statisticians. The following two interpolation methods were selected based on the assessment described in the DER:

- **Indicator Kriging (PCBs).** Indicator kriging was selected as the preferred method for PCB interpolation. Indicator kriging has been successfully applied to support RD and remedial action in the Lower Fox River, Green Bay, Wisconsin (Kern et al. 2008; Wolfe and Kern 2008; Anchor QEA and Tetra Tech 2016) and is recommended for use in sediment RD in Portland Harbor, Portland, Oregon (EPA 2022).

---

[7] Based on the results of the interpolation work described in the DER, PCBs were estimated to account for 88% of the RAL exceedance area in the upper reach. This percentage was calculated as the ratio of interpolated RAL exceedance area circumscribed by PCBs (in acres) to the total RAL exceedance area circumscribed by all COCs (see DER Appendix K Map K-4a).

[8] The maximum concentration in any shoaling interval or the -15 to -17 ft MLLW interval (i.e., 2 ft below authorized FNC depth in the upper reach of LDW) was selected for each shoaling core location.

- **Thiessen Polygons (Other COCs).** In localized areas, the RAL exceedance area boundary was expanded where other COCs exceeded RALs but PCBs did not. The RAL exceedance area boundaries for COCs other than PCBs were established using Thiessen polygons, a simpler geometric and deterministic interpolation method.

4.1.2 Horizontal Interpolation Results

Indicator kriging provides quantitative, probabilistic information directly in the interpolation output, and is a primary line of evidence for assessing the uncertainty of the PCB RAL boundary. The indicator kriging results represent the probabilities of exceeding the applicable depth-specific and area-specific PCB RALs, expressed in units of percent. The indicator kriging maps presented in the DER include contours ranging from 20% to 80% probabilities of exceedance, at 10% intervals (Maps K-3a through K-3c in DER Appendix K). Figures 4-1a through 4-1d show the 50% (median) PCB RAL exceedance boundary combined for both surface and subsurface sediments overlain with Thiessen polygons for other COCs where they extend beyond the PCB boundary[9].

The 50% probability of exceedance contour represents the median or central tendency estimate of the horizontal PCB RAL exceedance boundary (i.e., horizontal extent of contamination for PCBs). On the Fox River and Hudson River sediment cleanup sites, the median kriging estimate was similarly used to define the remediation boundary for RD and was shown to provide a reasonable balance between effectively remediating contaminated sediments above the RALs and minimizing the remediation of non-target sediments below the RALs (Thornburg et al. 2005; QEA 2007; Kern et al. 2008; Wolfe and Kern 2008; Anchor QEA and Tetra Tech 2016). The 50% (median) probability of exceedance contour plus Thiessen polygons for other COCs was therefore used as the minimum basis for setting RAA boundaries in the upper reach.

As described in Section 6 of this BODR, the RAA boundaries (i.e., remediation footprint) were expanded beyond the interpolated RAL 50% probability exceedance area boundaries to address engineering and constructability considerations. As a result, the expanded RAAs provide even greater confidence that RAL exceedances are being effectively addressed by RD.

In total, 35 distinct RAL exceedance areas were identified, as shown in Figure 4-2. These areas include RAL exceedances and interpolation-only areas.[10]

4.2 Vertical Extents of Contamination

The vertical extent of contamination within RAL exceedance areas was defined on a point-by-point basis using sediment core sample data and engineering judgment that considered the conceptual

[9] The RAL exceedance area presented in the DER for Area 29 has been updated in the BODR to correct an error in the Thiessen polygon interpolation for this area.

[10] Interpolation-only areas are defined as areas greater than 250 sq ft that do not include a sample location with a RAL exceedance.

site model and supplemental data (e.g., historical dredging depths in and adjacent to the FNC or berths, where available).

The ROD does not define RALs for vertical data collected deeper than the 0-45 cm or 0-60 cm intervals. The vertical extent delineation assumes that once an area has been designated for dredging, dredging would be advanced to a depth interval whereby the post-dredge surface (assessed as a 1-ft depth core interval) would not exceed the surface RALs (0-10 cm [0-4 inch] RALs). The bottom elevation of the deepest vertical core interval with concentrations greater than a surface RAL defines the bottom elevation of contamination. For cores that advanced into the native alluvium, the top of the native alluvium layer was sampled separately from the sediment above and was determined to be the vertical extent of contamination.[11]

Contamination was considered vertically bounded if there was at least one 1-ft sampling interval below the depth of contamination without surface RAL exceedances. When neighboring cores indicated a different vertical extent of contamination, the halfway point between the two cores generally defined the boundary over which each dredge elevation or thickness was applied.

To define the RAA vertical required dredge elevation, the vertical extent of contamination was adjusted downward (i.e., deeper removal) considering engineering factors such as constructability. Section 10.2.2 provides detail on how the vertical extent of contamination was translated into RAA vertical required dredge elevation or required dredge thickness for areas where dredging is the selected technology.

Additional vertical data will be collected in Phase III of the PDI to fill data gaps that have been identified in Preliminary (30%) RD. The Pre-Final (90% RD) will reflect the Phase III data and any associated adjustments to the RAAs.

[11] There were no RAL exceedances within vertical core intervals identified as native alluvium that were analyzed during the Phase II PDI (see DER Maps 3-4 series).

5 Remedial Technology Assignment

Remedial technology assignments were initially defined in the PDI QAPP Addendum and then updated in the DER. Remedial technologies assignments are assigned to each RAL exceedance area based on Figure 19 and Revised Figure 20 of the ROD, taking into account many factors including mudline elevation, RAL exceedance factor, depth of contamination, and recovery category designation.

Potential remedial technologies identified in the ROD for intertidal and subtidal areas include the following:

Intertidal:

- MNR below benthic SCO[12]
- MNR to benthic SCO[13]
- Area-specific technology
- ENR
- Partial dredge and engineered cap
- Dredge and backfill

Subtidal:

- MNR below benthic SCO
- MNR to benthic SCO
- Area-specific technology
- ENR
- Partial dredge and engineered cap
- Dredge (with backfill in habitat areas)
- Engineered cap

The preliminary remedial technology assignments from Table L-1 of the DER included multiple technology options for areas with data gaps or areas that spanned boundaries with different applicable technologies (e.g., intertidal/subtidal, recovery categories, large areas with varied sample results). For the Preliminary (30%) RD, the technology assignments have been updated based on available data, site condition information, and engineering considerations, and are summarized in

[12] Per the ROD, MNR below benthic SCO will be applied where the concentration of all COCs is less than the RAL and the RAO 3 cleanup levels (benthic SCO criteria), but greater than the human health-based (RAO 1 and 2) cleanup levels (which are measured on an LDW-wide or area-wide basis) (EPA 2014).

[13] Per the ROD, MNR to benthic SCO will be applied where the concentration of any of the 39 RAO 3 COCs (i.e., excluding the human health COCs PCBs and arsenic) is less than the RAL but greater than the RAO 3 cleanup levels (benthic SCO criteria; Table 27 of ROD), and modeling results indicate the COC will be reduced to the benthic SCO criteria within 10 years of the completion of remedial action (EPA 2014).

Table 5-1 and Figures 5-1a and 5-1b. Figure 5-2 shows sample locations where MNR to benthic SCO is applicable. MNR to benthic SCO RD areas will be defined following collection of Phase III PDI data.

Table 5-1
Preliminary (30%) Remedial Design Technology Assignments by RAL Exceedance Area

RAL Exceedance Area	Technology Assignment[1]	Notable Factors Impacting Technology Assignment and/or Phase III PDI Considerations
1	Dredge	Portion of area not vertically bounded; additional vertical sampling to bound contamination will occur in Phase III PDI.
2	Dredge	None.
3	Dredge	Area not vertically bounded in side slope west of FNC; additional vertical sampling to bound contamination will occur in Phase III PDI.
4	Dredge	None.
5	Dredge and ENR	An area-specific technology has been applied to a portion of the area due to adjacent structure. This includes a dredging offset from the South Park Bridge fender and ENR placement over the offset area.
6	Dredge	Interpolation-only area[2]. Will be verified during Phase III PDI.
7	ENR	None.
8	Dredge	None.
9	None	Interpolation-only area[2]. This area is not considered constructable and no remedial action is planned.
10	ENR	None.
11	Dredge	An area-specific technology has been applied to a portion of the area due to adjacent structure. This includes a dredging offset from the South Park Bridge fender. Potential action within the offset area (e.g., ENR placement) will be discussed and considered in later design phases, if appropriate. Area not vertically bounded; additional vertical sampling to bound contamination will occur in Phase III PDI.
12	Dredge	None.
13	Dredge and ENR	An area-specific technology has been applied to a portion of the area to avoid impacts to the armored slope. This includes ENR placement over the armored slope and dredging adjacent to the armored slope.
14	Dredge	None.
15	Dredge	None.
16	Dredge	Area not vertically bounded; additional vertical sampling to bound contamination will occur in Phase III PDI.
17	Dredge	None.
18	Dredge, partial dredge and engineered cap, and ENR	An area-specific technology has been applied to a portion of the area due to adjacent structures. This includes a dredging offset from the bulkhead and cap placement over the northern extent of the offset area and ENR placement over the southern extent of the offset area.
19	Dredge	Area not vertically bounded; additional vertical sampling to bound contamination will occur in Phase III PDI.

RAL Exceedance Area	Technology Assignment[1]	Notable Factors Impacting Technology Assignment and/or Phase III PDI Considerations
20	Dredge	None.
21	Dredge	Interpolation-only area[2]. Will be verified during Phase III PDI.
22	Dredge	Area-specific technology may apply due to adjacent structure. This includes removing surficial debris and dredging to the extent practicable. A dredging offset may be applied and will be reviewed further in Intermediate (60%) RD.
23	ENR	None.
24	Dredge and ENR	An area-specific technology has been applied to a portion of the area due to adjacent structure(s). This includes a dredging offset from the bulkhead and ENR placement over the offset area.
25	ENR	None.
26	Dredge and ENR	An area-specific technology has been applied to a portion of the area to avoid impacts to the armored slope. This includes ENR placement over the armored slope and dredging adjacent to the armored slope.
27	Dredge	None.
28	Dredge	Although the current Slip 6 elevations are within the range of habitat elevations defined in the ROD, Slip 6 is a permitted berth. Therefore, dredge areas will not be backfilled for habitat purposes.
29	Dredge	None.
30	Dredge	None.
31	Dredge	Area not vertically bounded; additional vertical sampling to bound contamination will occur in Phase III PDI.
32	Dredge	An area-specific technology has been applied due to access limitations and constructability concerns due to presence of an over-steepened bank slope. This includes removing surficial debris, dredging to the extent practicable, placing a clean layer, and armoring the slope.
33	ENR	None.
34	Dredge	Area-specific technology may apply due to access limitations and constructability concerns due to presence of an over-steepened bank slope. This includes removing surficial debris, dredging to the extent practicable, placing a clean layer, and armoring the slope.
35	Dredge	An area-specific technology has been applied due to access limitations and constructability concerns due to presence of an over-steepened bank slope. This includes removing surficial debris, dredging to the extent practicable, placing a clean layer, and armoring the slope.

Notes:
1. The technology assignment of "dredge" also requires backfill to restore existing grade in habitat areas (i.e., -10 ft MLLW and above).
2. Interpolation-only areas are artifacts from the interpolation analysis and do not include a sample location with an RAL exceedance.

ENR: enhanced natural recovery
FNC: federal navigation channel
PDI: pre-design investigation
RAL: remedial action area
ROD: Record of Decision

6 Remedial Action Areas Development

Following assignment of remedial technologies, areas with RAL exceedances were developed into RAAs based on three primary considerations: engineering considerations, review of adjacent chemistry results, and constructability of the assigned technology. Additionally, review of potential RAL exceedance area boundary uncertainties was performed as a modifying consideration. The Preliminary (30%) RD RAA extents were then defined using engineering best professional judgment. These processes are described in the following subsections.

6.1 Engineering Considerations

One step in the RAA development process involved reviewing the interpolated RAL exceedance area boundaries with the overlaying engineering design factors. These design factors vary slightly for each of the different remedial technologies, but generally result in the RAA boundaries that are more linear (e.g., straight lines) and expand the remedial action footprint to encompass a larger area compared to the RAL exceedance areas.

In some locations, engineering considerations result in a RAA boundary that is inside the interpolated RAL exceedance area boundary; for example, where construction offsets from structures or armored slopes will be required to protect structures or armored slopes. Areas where the RAA boundary may not capture the full interpolated RAL exceedance area boundary are discussed in Table 6-1.

The engineering considerations described in the following subsections were used to define the Preliminary (30%) RD RAA boundaries.

6.1.1 Geometry Considerations

For RAAs where dredging or partial dredging and capping are the planned remedial technology, RAL exceedance areas were enclosed by dredging toe of cut boundary lines composed of straight lines and constructable angles for dredging feasibility. The toe of cut represents the boundary where the contractor will be required to conduct full vertical depth removal. The toe of cut is set at or outside of the RAL exceedance area boundaries (i.e., typically captures a larger area than the RAL exceedance area). For ENR placement areas, the RAA boundaries were not squared off in straight lines since material placement over irregular shapes is less challenging than material removal, but a 10-ft horizontal buffer was added around the RAL exceedance area boundary when developing ENR RAAs.

6.1.2 Site Physical Conditions

Factors including but not limited to slopes, berthing depth requirements, presence of debris, presence of armored slopes, and presence of structures in the uplands adjacent to a bank were also considered. For example, when a RAL exceedance area is present on a sloped area, the RAA boundaries were developed using straight lines that were drawn parallel and perpendicular to existing contours to the extent possible. This was done to define action areas that are more stable for dredging and backfilling, and to provide dredge prisms that are easier to measure during construction to confirm that the contractor is complying with design plans and specifications.

Site physical conditions specifically consider slope stability and offsets as follows:

1. **Sediment stability/side slopes:** Following definition of the toe of the dredge cut for dredge prisms, side slopes were established to leave a stable post-dredge surface. The side slope is the area over which the dredge cut slopes up from the dredge elevation/depth to meet the existing mudline. This slope is defined by recommendations from the geotechnical analyses (see Section 8).
2. **Structure or armored slope offsets:** For dredging areas, horizontal offsets from structures (e.g., South Park Bridge, Boeing Isaacson bulkhead, Centerpoint Properties bulkhead) and armored slope toes (e.g., South Park Marina armored bank) were included based on a review of available data compared to dredge depths. Horizontal offsets represent an area adjacent to the structure/armored slope that needs protection where no dredging or excavation will be allowed to prevent adverse impacts to the adjacent structure/armored slope[14]. The offset distance includes a horizontal offset from the top of the daylight cut, which is where the dredge cut side slope intersects the existing mudline. For ENR and cap material placement areas, no offsets are assumed to be necessary for Preliminary (30%) RD.
3. **Utility offsets:** Based on a records review, public and private utility locate, and property owner outreach during Phase II PDI activities, only one active submarine utility line was identified in the upper reach. This line is located within the footprint of the South Park Bridge and is at an elevation well below planned dredging activities. Therefore, no offsets were defined for dredging in this area. An abandoned line associated with the former South Park Bridge was identified to be a waterway buried crossing in the area, though detailed drawings and information were not located to determine the elevation in which the line crossed the LDW. For Preliminary (30%) RD, this abandoned line is presumed to be much deeper than planned dredging. Similar to the approach implemented during the Boeing Plant 2 EAA dredging, no offset has been defined related to this abandoned line. Further research to obtain utility crossing information for this abandoned line will occur during Intermediate (60%) RD.

6.1.3 Adjacent Early Action Areas, Upland Site Cleanup, and Habitat Site Conditions

1. **Adjacent EAAs**: RAAs bordering EAAs were evaluated based on the horizontal and vertical extent of EAA post-dredge surfaces. In cases where buried contaminated material is interpreted

[14] Offsets are discussed further in Sections 8 and 9. A 10-ft offset from structures is being used in Preliminary (30%) RD and will be refined during Intermediate (60%) RD, if appropriate, after structure-specific analyses are conducted.

to potentially remain between the RAA dredge prism and EAA post-dredge surface, RAA boundaries were expanded to create a continuous remedy.

2. **Upland site cleanups**: As discussed in Section 2.2, there are five upland cleanup sites (four Ecology-led and one EPA-led) that are adjacent to LDW upper reach RAL exceedance areas. The remedy for two of the RAL exceedance areas will need to be further assessed and coordinated with the upland site. For Preliminary (30%) RD, the following design assumptions have been made to develop the RAAs:
    a. **Area 13 (adjacent to South Park Marina upland site; see Sheet C03 in Appendix D):** The RAL exceedance boundary in Area 13 was developed using data that are likely not representative of current conditions, based on a more detailed review of the as-built data from the adjacent EAA at T-117. The T-117 as-built survey indicates that sediments in the location of the existing data were dredged. Additional data will be collected during Phase III PDI to characterize the current condition in this location and to adjust the Area 13 RAL exceedance boundary as appropriate. In addition, due to the presence of an engineered armored slope, only a portion of the area can be dredged without creating stability concerns. Therefore, the dredging top of slope cut has been set at the edge of the armoring, and ENR placement will occur over the armored slope. An assessment of additional measures (e.g., sheetpile wall installation) will be considered during future design phases, in addition to continued coordination with the upland site cleanup process, to integrate the upland (if necessary) and sediment site cleanups.
    b. **Area 18 (adjacent to Boeing Isaacson Thompson upland site; see Sheet CP01 in Appendix D):** Due to unbounded contamination adjacent to a deteriorating bulkhead and understanding of the adjacent upland remedial design progress, several options are explored in Section 10.3.2. The preferred option is to integrate the adjacent upland cleanup with the in-water remedy, which would defer Area 18 remedial action. For the purposes of developing the RAA for Preliminary (30%) RD, this area assumes a partial dredge and an engineered cap. The dredging top of slope has been set 10 ft from the bulkhead, and the cap will cover the offset area and the slope of the cut, as discussed in Section 10.3. Additional coordination with the upland site cleanup will occur in future design phases to evaluate potential options for integrating the upland and sediment site cleanups. Further discussion of design options for Area 18 is included in Section 10.3.2.
3. **Habitat Areas**: Information from recently constructed habitat areas (e.g., Duwamish River People's Park and Habitat Area project) was reviewed to set or adjust RAA boundaries along the habitat areas to provide for a logical transition between habitat areas and the adjacent RAA.

6.1.4 *Review of Other Available Engineering Information that Informs the Physical Conceptual Site Model*

Review of the USACE historical post-dredge and condition survey records, which indicated maintenance dredging extended horizontally beyond the FNC in some locations during prior dredge events, led to adjustment of the RAA toe of cut in specific areas. One RAA (Area 1/2/3) was adjusted to set the RAA boundary inside the RAL exceedance area boundary to best match the RAA removal extents with the historical dredging records in those areas.

6.2 Review of Adjacent Chemistry Results

Another step in developing RAAs involved reviewing design dataset sampling results immediately outside of the RAL exceedance areas. Sample results near RAL exceedance areas were reviewed on a point-by-point basis, and engineering best professional judgement was used to decide if and how far to extend the RAA boundary. Specifically, samples that were close to exceeding the RAL (i.e., between a RAL exceedance factor of 0.9 and 1) were reviewed with respect to proximity to RAL exceedance areas and magnitude of nearby exceedances. Data density was also considered when looking at specific areas where expansion of RAAs beyond the initial engineering considerations could be warranted.

6.3 Constructability

After defining RAAs based on engineering considerations and a review of adjacent data, areas were reviewed from a holistic perspective to identify potential constructability issues and to reduce complexity from a contractor's constructability standpoint. Constructability refers to the ease and feasibility for a remediation contractor to construct the RD and is affected by the type of equipment the contractor uses, physical site conditions, and ability by the Implementing Entity to effectively monitor and measure the contractor's work. Similar to engineering considerations, constructability considerations typically expand the area covered by an RAA (compared to the RAL exceedance area). Areas where the RAA boundary may not capture the entire RAL exceedance area boundary are discussed in Table 6-1.

Modifications to RAAs to address constructability considerations include the following:

- Merging of areas in close proximity to one another (e.g., Areas 1/2/3, Areas 15/16): Leaving small areas between RAAs will complicate construction and reduce efficiency. Remediating those small areas can also help address other practical considerations such as residuals management requirements.
- Incorporating small areas that are contained within a large RAL exceedance area but that the interpolation predicts there is not a RAL exceedance: While these small interior areas with no RAL exceedances do not require action, the RD assumes that including these areas (e.g.,

Area 18 south end, Area 27) will result in overall more efficient and cost-effective removal than relying on the dredging precision that would be necessary to exclude these areas.
- Considering equipment access limitations: Site restrictions that may limit the ability for equipment access will be evaluated to avoid specifying a remedial action that is not feasible to construct due to equipment inaccessibility.

6.4 RAL Exceedance Area Boundary Uncertainty Considerations

The following methods were used to identify uncertainty in the interpolation used for identifying RAL exceedance area boundaries:

- As noted in Section 4.1.2, the 50% probability of exceedance contour represents the median or central tendency estimate of the horizontal PCB RAL exceedance boundary (i.e., horizontal extent of contamination), and generally optimizes correct predictions and provides a reasonable balance between effectively remediating sediment above the RALs and minimizing the remediation of non-target sediment below the RALs (QEA 2007; Kern et al. 2008; Wolfe and Kern 2008; Anchor QEA and Tetra Tech 2016). The 50% (median) probability of exceedance contour for PCBs in combination with Thiessen polygons for other COCs (i.e., RAL exceedance areas) was therefore used as the starting basis for setting RAA boundaries.

- During development of the Preliminary (30%) RD RAAs, the RAA boundaries were compared at a high level against the RAL exceedance area probability of exceedance contour banding maps that showed probability of exceedances from 20% to 80%. That banding shows areas with higher and lower levels of uncertainty from the starting basis for setting the RAA boundaries.

- Additional cross-validation evaluation of the RAL exceedance area interpolation (Anchor QEA and Windward 2022a) was conducted to help identify potential locations of Phase III PDI data gap sampling to reduce potential interpolation uncertainty.

Engineering best professional judgment was used to set the RAA boundaries and considered the probability of exceedance results to be a modifying factor to the primary engineering, adjacent sediment chemistry, and constructability considerations described previously. Preliminary (30%) RD extended the RAA boundaries beyond the RAL exceedance areas in most locations to address the three primary design considerations. Lastly, the probability of exceedance bands were compared against the preliminary RAA boundaries, and adjustments were made to the RAA boundaries if multiple lines of evidence suggested the RAA boundary should be adjusted to capture additional specific areas of greater uncertainty. Figures 6-3a through 6-3c show the boundaries of RAL exceedance areas, probability of exceedance bands (20% to 80%), and the Preliminary (30%) RD preliminary RAA boundaries. As the figures show, the RAA boundaries typically extend well beyond the RAL exceedance area boundaries due to design considerations for engineering factors, adjacent sediment chemistry, and constructability. This expansion of the RAA boundaries addresses much of the potential uncertainty in the interpolation, effectively removing much of the area with 40% to 30% probability of exceedance, and provides a high level of confidence in achieving the intent of the ROD and the effectiveness of the RD.

The Phase III PDI QAPP Addendum will address remaining data gaps identified through Preliminary (30%) RD development and review. The results from Phase III PDI (and associated re-interpolation) will be used to inform potential revisions to Preliminary (30%) RD RAA boundaries at Pre-Final (90%) RD.

6.5 Summary of Remedial Action Areas

RAAs for the upper reach are shown in Figures 6-1a and 6-1b. Additionally, Figures 6-2a through 6-2j show the RAA boundaries in relation to the design dataset sample locations and results. Table 6-1 summarizes the unique or specific considerations for each RAA beyond the general considerations described in Section 6.1. Appendix B discusses one additional RAA for an area where the 2014 ROD carcinogenic polycyclic aromatic hydrocarbon (cPAH) RALs are exceeded.

The total surface area of the RAL exceedance areas, delineated as described in Section 4, is 339,500 sq ft (or 7.8 acres). For comparison, the total surface area of the RAAs is 635,700 sq ft (14.6 acres), which is an 87% increase from the RAL exceedance areas.

RAL exceedance area numbering presented in the DER has been retained for Preliminary (30%) RD. For areas that have merged, the RAA is referred to using both numbers (i.e., “Area 2/3”). The RAA numbering will be revised during Intermediate (60%) RD following input from EPA on the Preliminary (30%) RD.

Table 6-1
RAA Development Considerations

RAA	Area-Specific RAA Development Considerations[1]
1/2/3	• Western toe of slope adjusted to account for maximum horizontal extent of USACE historic dredging records (30 ft beyond FNC based on similar extents of dredging from the 1958 and 1965 USACE post-dredge conditions surveys). • Eastern boundary expanded to overlap with Boeing Plant 2 EAA based on review of as-built survey data. • Areas 1/2/3 merged due to proximity and associated constructability.
4/5	• Eastern boundary expanded to overlap with Boeing Plant 2 EAA based on review of as-built survey data. • Areas 4/5 merged due to proximity and associated constructability. • Non-RAL exceedance areas (near locations 118, 119, and 528) encompassed within RAA due to constructability considerations. • Non-RAL exceedance areas (one east of location 529 and one under the South Park Bridge) encompassed within RAA due to constructability considerations. • Dredging offset from South Park Bridge fenders applied; ENR to be placed in offset area.[2]
6	• This is an interpolation-only area/Phase III data gap.
7	• No area-specific considerations.
8	• No area-specific considerations
9	• This is an interpolation-only area and not considered constructible; remedial action is not planned in this area.
10	• No area-specific considerations.
11	• Dredging offset from South Park Bridge fender applied.[2]
12	• No area-specific considerations.
13	• RAL exceedance boundary may not be based on representative data; new data will be collected during Phase III PDI and the RAL exceedance boundary adjusted as appropriate. See Section 6.1.3 for further explanation. • Dredging offset from armored slope applied; ENR to be placed on armored slope[2]. • Coordination of remedy with adjacent upland cleanup process is necessary and an integrated upland/in-water remedy, if appropriate, will be developed that will follow a timeline compatible with the upland cleanup process.
14	• Separation maintained from Area 15/16 because mid-channel samples are below RALs (SC205, SC207, and SC210 shoal intervals). • Review of Boeing Plant 2 EAA post-dredge data confirms the eastern boundary matches EAA dredge limits.
15/16	• See note for Area 14 regarding separation of areas. • Areas 15/16 merged due to proximity and associated constructability. • Review of T-117 EAA post-dredge data confirms the western boundary matches EAA dredge limits.
17	• Review of Jorgensen Forge EAA post-dredge data confirms the eastern boundary matches EAA dredge limits.

RAA	Area-Specific RAA Development Considerations[1]
18	• Non-RAL exceedance areas (near locations 228, 229, and 593) encompassed within RAA due to constructability considerations. • Dredging offset from sheetpile wall applied. • Coordination of remedy with adjacent upland cleanup to continue. • Coordination of remedy with adjacent upland cleanup process is necessary and an integrated upland/in-water remedy, if appropriate, will be developed that will follow a timeline compatible with the upland cleanup process. • If coordination between the upland and in-water cleanups is not possible, the Preliminary (30%) RD assumes capping material to be placed along Port of Seattle sliver property and ENR material to be placed along remainder of the offset area in southern portion of Area 18.[2]
19/20	• Areas 19/20 merged due to proximity and associated constructability. • Western toe moved 10 ft to the east to avoid impacts to new habitat construction and steep slope.
21	• This is an interpolation-only area/ Phase III data gap.
22	• Adjacent ENR and ENR/AC pilot plots limit exceedance area and RAA. • Debris removal area adjacent to sheetpile wall.
23	• No area-specific considerations.
24	• Dredging offset from sheetpile wall applied; ENR to be placed in offset area.[2, 3]
25	• No area-specific considerations.
26	• Dredging offset from armored slope applied; ENR to be placed in offset area.[2]
27	• Non-RAL exceedance areas (northern end of Area 27, near location 658, and near locations 664 and 665) encompassed within RAA due to constructability considerations. • Eastern boundary set at toe of slope.
28	• Discrete areas within Area 28 merged due to proximity and associated constructability.
29	• No area-specific considerations.
30	• No area-specific considerations.
31	• No area-specific considerations.
32, 34, 35	• Interpolation extrapolated to MHHW line up steep armored bank; eastern toe adjusted accordingly (see Section 4.1 for further discussion). • ENR to be placed where sediment removal is impractical.
33	• No area-specific considerations.

Notes:
1. Area-specific RAA considerations are in addition to practical engineering considerations, review of adjacent chemistry results, constructability of the assigned technology, and RAL exceedance area boundary uncertainties, as described in Section 6.1.
2. Dredging offset areas are identified where dredging was determined to likely result in armored slope or structure instability or potential failure. Depending upon detailed structural and geotechnical analyses that will be prepared during Intermediate (60%) RD, dredging offset areas may warrant no action, placement of ENR materials, capping (assuming raising bed elevations from capping is allowable), or require temporary shoring to facilitate some dredging. For Preliminary (30%) RD, ENR materials were assumed to be placed over the dredging offset areas. Use of ENR materials over dredge offset areas has been determined to be a reasonable approach for similar sediment remediation projects.
3. A new RC 1 area was added just south of ENR/AC plot. This occurred after the interpolation modeling to develop RAL exceedance areas. This area will be re-evaluated for RAL exceedances when the interpolation model is re-run during Pre-Final (90%) RD.

AC: activated carbon
EAA: early action area
ENR: enhanced natural recovery
MHHW: mean higher high water
RAA: remedial action area
RAL: remedial action level
RD: remedial design
USACE: U.S. Army Corps of Engineers

7 Sediment Management Areas Design Considerations

Sediment Management Areas[15] (SMAs) will be developed in Intermediate (60%) RD to facilitate construction management by organizing the overall project into more manageable areas. SMAs do not change the RAA extents, rather they provide a consistent nomenclature for referring to areas in design and construction management. Generally, SMAs will consist of grouped or subdivided RAAs with similar logistical considerations such as common construction methods, adjacent locations, and similar site conditions. SMAs will be used in the design drawings to define discrete areas for construction management (e.g., construction sequencing, determining the completion and acceptance of the remedial actions).

SMA designations are based on engineering judgment. Factors that affect SMA delineation include recontamination risk of remediation areas and adjacent areas during construction, technology types and construction methods, and administrative and site access considerations, as discussed in the following subsections.

7.1 Recontamination Risk During Construction

The development of SMAs will consider the potential for recontamination of remediated areas and adjacent areas that are not actively remediated as the construction progresses. The following considerations will be reviewed to develop SMAs that limit the risk of recontamination during construction:

- The proximity of RAAs to each other
- Potential vessel propwash from contractor operations
- Remedial technologies being used (i.e., dredging and placement activities)
- The phasing of dredging and placement activities
- Construction activities occurring over multiple in-water work seasons

If it is determined that RAAs have the potential to pose a recontamination risk to one another, this would be a reason to combine these RAAs within one SMA such that the sequencing of the work within the individual SMA can be completed in an appropriate order to reduce the potential for recontamination.

7.2 Technology Types and Construction Methods

The type of remedial technology or equipment used to implement the remedy at a specific location will also be a factor in developing SMAs. There is a preference to consolidate and complete areas

[15] Sediment Management Areas for remedial design are used in a different context than described under Washington State Sediment Management Standards. Under these standards, SMAs support cleanup decision making during the RI/FS. For the remedial design described in this BODR, SMAs are used to organize the design for other reasons as described in the RDWP.

with similar technology types at the same time within the construction sequence to improve quality control. Dredging activities would generally be performed before placement activities.

7.3 Administrative and Site Access Considerations

Administrative considerations will also be considered in developing the SMAs, including site access constraints and property ownership. Combining areas with similar administrative considerations will facilitate efficiency by allowing for work with similar constraints to be completed together, limiting interruptions to waterway activities.

SMAs may also serve as areas over which remedy construction performance can be evaluated, contingency actions can be performed as needed, and areas can be determined complete as the cleanup progresses.

8 Geotechnical Engineering Considerations

This section presents the results and recommendations of the geotechnical engineering evaluations for the LDW upper reach. Appendix C presents a more detailed discussion of the geotechnical engineering evaluations completed to support Preliminary (30%) RD.

8.1 Geotechnical Field Investigation Summary

Subsurface geotechnical conditions at the site were investigated by Anchor QEA as part of the Phase I and Phase II PDI efforts completed in 2021 and 2022. The DER and Appendix C of the BODR describe the geotechnical investigation and results.

The locations of these geotechnical investigations are presented in Figures 8-1a and 8-1b. Additional details, including boring logs, in situ testing data, and results of laboratory geotechnical testing results, are presented as attachments to Appendix C.

8.2 Subsurface Stratigraphy

This section describes the three major geologic units encountered during the geotechnical PDI. Subsurface conditions encountered during the geotechnical investigation are in general agreement with those presented in the RI/FS and consist of recent sediments overlying alluvium within the waterway. Fill material was encountered overlying the alluvium unit in upland locations, and based on the history of river realignment, it is expected to be present in shoreline bank areas to below MLLW where the historic river channel was filled and in other shoreline locations where the grade was raised to support upland development.

General descriptions of the soil and sediment layers and their geotechnical characteristics identified from the borings and investigations advanced at this site are presented below in order from the ground surface downward.

8.2.1 Fill

Fill soils were encountered at two locations during the Phase II PDI field program, and at several other upland locations investigated for other projects. Generally, this material was placed in early 1900s to regrade the existing fluvial plain created by the Duwamish River to support shoreline development and the re-channelization of the river. The unit weight of this material is assumed to vary, but for preparing design recommendations it is assumed to be conservatively represented using an overall average value of 135 pounds per cubic foot (pcf), based on laboratory direct shear test results of sample intervals identified as fill. Grain size distribution testing shows that this material is mostly sand, with varying amounts of silt. In areas where fill was more randomly or recently placed, the fill is expected to contain anthropogenic materials such as debris, which would be typical of historic shoreline development filling activities in active industrial areas. The moisture content in the fill unit generally ranges from 6% to 28%. Direct shear testing of the fill indicates a peak friction angle average of 36 degrees and a residual friction angle average of 33 degrees.

The findings associated with the two upland borings completed by Anchor QEA in 2021 are in general agreement with historical investigations completed by others.

8.2.2 Recent Sediments

Recent sediments were encountered throughout the intertidal and subtidal areas. Recent sediments were naturally deposited by river flows entering the upper reach from upstream following the creation of the waterway.

The thickness of this unit across the site varies widely and is thickest in areas of historical dredge activities. Based on a review of laboratory testing results, a total unit weight of 100 pcf was assumed to best represent average overall conditions, with percent moisture content ranging from 34% to 97%. Atterberg limits (plasticity) testing indicates that this material is typically nonplastic to very low plasticity, an indication that the finer fractions are mostly silt rather than clay. Direct shear testing indicates a peak friction angle of 34 for the recent sediments, and a residual friction angle of 33 degrees. Vane shear testing and full flow penetrometer testing indicate undrained shear strengths ranging as shown in Figure 2-1 of Appendix C. Grain size analyses indicate that this material is approximately 30% sand, 70% silt and clay, with silt content ranging from 22% to 62%, and clay content ranging from 2% to 7%.

8.2.3 Alluvium

Investigations prior to the PDI describe the alluvium in reference to an upper unit and a lower unit. In the DER, the description of the alluvium was combined into a single unit, recognizing that there are some gradational changes in the alluvium with depth. Alluvium was observed to underlie the recent sediments and is mostly coarse-grained material with pockets, lenses, and layers of silt and clay. Silt content of the fine-grained layers is as high as 76%, and clay content is as high as 16%. Silt and clay content in the mostly coarse-grained material was observed to be as low as 1.5% within this unit. This unit has a typical specific gravity of 2.5 to 2.7, is nonplastic, has a typical total unit weight of 125 pcf, and has a measured average peak friction angle of 37 degrees and a measured average residual friction angle of 32 degrees.

The alluvium unit was the deepest layer encountered during the geotechnical PDI.

8.3 Geotechnical Engineering Design Recommendations

This section summarizes the results and design recommendations based on the geotechnical analyses presented in Appendix C for the following:

- Dredge prism side slope stability
- Backfill side slope stability
- Cap bearing capacity, settlement, and slope stability
- Lateral earth pressures for bulkhead evaluations
- Geotechnical recommendations for pile design
- Bank slope stability
- Seismic performance of caps

Details regarding the processes, assumptions, models, and approach used to develop the geotechnical engineering design recommendations are provided in Appendix C. The following sections describe the results of these analyses as they relate to RD.

8.3.1 Dredge Prism Side Slope Stability

Dredging is required on intertidal and subtidal slopes, and dredge cuts also require side slopes to reach the design removal elevation or depth. The stability of dredge prism side slopes was evaluated using limit equilibrium methods implemented by the Rocscience SLIDE2 software (SLIDE).

Target slope stability factors of safety are 1.3 for short-term conditions (e.g., a dredge cut before backfill is placed) and 1.5 for long-term conditions (e.g., a final post-backfill slope angle) in accordance with USACE (2003) and as described in Appendix C. As described in Appendix C, temporary side slopes of 2H:1V and permanent unarmored side slopes of 3H:1V have acceptable factors of safety, while steeper permanent side slopes can be achieved using armor rock.

8.3.2 Backfill Side Slope Stability

Backfill will be placed following dredging in habitat areas (i.e., elevations higher than -10 ft MLLW). In deeper dredging areas, there will be a backfill slope that transitions from the backfill downward to meet the post-dredge surface below elevation -10 ft MLLW. Backfill may also be used following steeper temporary cuts that would be made to limit the removal of clean slope materials (e.g. transition slopes adjacent to the Boeing EAA where clean backfill was placed). As described in Appendix C, backfill side slopes of 3H:1V have an acceptable slope stability factor of safety for sand and gravel habitat materials. Steeper backfill slope angles (up to 2H:1V) have acceptable factors of safety in cases where armor rock is used.

8.3.3 *Cap Bearing Capacity, Settlement, and Slope Stability*

Cap subgrade bearing capacity and post-construction cap settlement were assessed for proposed 4-ft-thick caps. The static slope stability of a cap at RAL exceedance area 18 was also evaluated using limit equilibrium methods.

Caps will typically be constructed after dredging and in most cases will not raise the ground surface above the existing grade. As such, caps constructed under these conditions will balance out the subgrade loads by replacing the load imposed by the dredged sediment (unloading the subgrade) with a load imposed by the cap. For these conditions, the bearing capacity of the subgrade to support the cap is judged to be acceptable, and the settlement caused by the cap load is estimated to be on the order of 2 to 3 inches.

In limited circumstances, caps may need to be constructed with a final surface above the existing grade, in particular for offset areas where dredging cannot be accomplished against structures. Appendix C describes bearing capacity and settlement evaluations for these circumstances where dredging will not occur prior to cap construction.

In summary, the major conclusions of this evaluation presented in Appendix C are as follows:

- A 4-ft-thick cap has acceptable bearing capacity factors of safety.
- Post-cap subgrade settlement in dredge areas is estimated to range from 2 to 3 inches.
- Post-cap subgrade settlement in dredge offset areas is estimated to range from 5 to 10 inches.
- The majority of post-cap subgrade settlement is estimated to occur within 120 days after cap construction.
- A cap constructed in RAL exceedance area 18 has an acceptable static slope stability factor of safety.

8.3.4 *Lateral Earth Pressures for Bulkhead Evaluations*

Lateral earth pressure recommendations were developed to support structural evaluations for existing bulkheads. Structural evaluations, in turn, are used to develop recommendations regarding dredging and capping adjacent to existing bulkhead structures, and to assess whether offsets or other measures are needed to protect bulkheads. Appendix C presents specific lateral earth pressure recommendations for structural design evaluations.

Lateral earth pressure design recommendations for new bulkhead structures will be developed for specific cases in subsequent design phases in the event that replacement of existing bulkheads is necessary.

8.3.5 Evaluation of Dredging Offsets from Structures

As described in Appendix C, dredging immediately adjacent to shoreline structures will reduce the lateral support provided by the sediment adjacent to the structure (i.e., the passive earth pressure). Reduction in passive earth pressure can cause structural damage if not appropriately considered in the RD. One way to limit or prevent the reduction of passive earth pressure is to offset the dredge cut a sufficient distance from the structure. This section provides a summary of the dredging offset evaluation that is described in more detail in Appendix C.

The extent to which passive earth pressure is reduced by adjacent dredging is a function of the offset distance, the depth of dredging, and the slope angle of the dredge cut. Appendix C presents the following conclusions from this evaluation:

- Without a dredging offset, passive earth pressures are reduced from 38 to 75 percent of full passive earth pressure for dredge slope cuts ranging from 1H:1V to 2H:1V.
- A horizontal dredging offset of at least 5 ft will limit the potential for reducing passive earth pressure. The Preliminary (30%) RD assumes a 10-ft offset from structures, which considers the geotechnical evaluation as well as additional safety measures that will limit the potential for dredging equipment to physically contact and potentially damage structures.
- Passive earth pressure reduction factors are presented in Appendix C for use during structural evaluations conducted during intermediate (60%) RD to consider whether any structures can tolerate a dredging offset that is closer than 5 ft.

8.3.6 Geotechnical Recommendations for Piling

Pilings are anticipated to be removed and replaced to facilitate access for dredging at some locations. In particular, some of the floats at the South Park Marina, including guide piles, will need to be removed for access to Area 13. Similarly, piles within the timber groin structures near Areas 32 to 35 are assumed to be demolished, although alternative approaches for the timber groin structures may be considered during Intermediate (60%) RD. There may also be a need for isolated pile removal for derelict piles that do not have any identified current or future use but may be inhibiting access for nearby remediation

Replacement piles are expected to support lateral loads from river currents and boat traffic. Any piles that are removed that support net fishing will also be replaced and designed to resist forces imposed by the nets, which will be evaluated in coordination with tribal fishers. The need for vertically loaded replacement piles has not been identified. Piles are assumed to be replaced to provide "in kind" functions to piles that are removed; however, timber piles will be replaced with steel piles during reconstruction.

To support structural engineering evaluations, geotechnical design recommendations for replacement piling are presented in Appendix C. The recommendations include modeling parameters to be used in lateral pile design analysis software (i.e., LPile) so that pile deflection and embedment can be determined by the structural engineer. Results of these evaluations will inform the sizing (diameter, wall thickness, and length) of the replacement piles, which will be provided in the Intermediate (60%) structural RD submittal.

8.3.7 Bank Slope Stability

The RD includes dredging near existing waterfront facilities and shorelines. Dredging removes sediments that support the toe of the slope and hence the resisting force against a potential sliding mass.

8.3.7.1 Area 13

Bank stability is relevant to dredging of Area 13 in the South Park Marina, where existing bank slopes have reportedly been marginally stable. To assess slope stability in Area 13, a geologic model was developed and stability analyses were performed as described in Appendix C. The major conclusions from this evaluation are as follows:

- The long-term factor of safety for the existing slope configuration is marginally higher than 1.0. This conclusion is consistent with reports that the slope in this area is considered only marginally stable. Engineered slopes typically have a factor of safety of at least 1.5.
- The short-term factor of safety (during construction) for the proposed dredge cut is less than 1.0. This suggests that, for the modeling assumptions used, the dredge cut cannot be accomplished without destabilizing the slope.

Because the short-term factor of safety is below 1.0, the design of the dredge cut at Area 13, as presented in the Preliminary (30%) RD, will need to be refined. The following are several options to be considered for refining the design in this area:

- Flatten the dredge cut side slopes. This refinement alone may not be sufficient to achieve an acceptable short-term factor of safety.
- Offset the dredge cut sufficiently so that the dredge cut does not influence the short-term stability of the adjacent slope. This refinement would not accomplish full removal of material exceeding RALs in Area 13.
- Reduce the depth of required dredging in this area. Based on conversations with representatives of the South Park Marina, the marina is considering a reduced berth depth in this area to help mitigate issues associated with the marginally stable slope in this location. This refinement would presumably require a post-dredge cap.
- Install temporary shoring such as a sheetpile wall at the toe of slope. The dredge cut would likely need to be backfilled and the overall slope would continue to be marginally stable after the shoring is removed. In addition, vibrations associated with installation and removal of sheeting would need to be considered.

- Collect additional subsurface geotechnical information on the slope in this area. The model currently assumes the slope beneath the riprap consists of recent sediments, which have relatively low undrained shear strength. If geotechnical conditions in this area are better than assumed for Preliminary (30%) RD, the slope stability factor of safety would improve. However, because this area has been observed to be marginally stable, it is not expected that additional data collection would significantly improve the modeling conclusions.

8.3.7.2 Other Bank Areas

For other bank areas, it is assumed that minor thickness cuts (i.e., 1 to 2 ft below existing grade) can be made while maintaining an acceptable bank slope stability factor of safety. If needed, more detailed slope stability of additional bank areas will be assessed in subsequent phases of RD.

8.3.8 Seismic Performance of Caps

The upper reach lies in a seismically active region and is characterized by sources of strong ground shaking (earthquakes) including the Cascadia Subduction Zone and relatively shallow crustal zones such as the Seattle fault zone. Seismic performance of caps was evaluated by considering liquefaction potential and estimating liquefaction-induced settlement, and by evaluating seismic stability of caps on slopes and estimating potential deformations (movement) of caps on slopes during an earthquake.

Two different earthquakes were evaluated. The 100-year return interval earthquake was evaluated, consistent with the 100-year modeling timeframe considered for contaminant transport evaluation. In addition, the larger, 475-year earthquake was considered. This larger earthquake has a 10% probability of exceedance in a 50-year timeframe and is a commonly considered earthquake for Superfund sediment remedies. The following summarizes the major conclusions of the seismic performance evaluation:

- Liquefaction is predicted under both the 100-year and 475-year earthquakes. Liquefaction results in loss of soil strength and settlement.
- Cone penetrometer test records were analyzed for liquefaction-induced settlement; predicted settlements range from 3 to 14 inches (median settlement 7 inches) under either earthquake scenario.
- Post-earthquake deformation of caps on slopes is predicted to range from 1 to 2 inches following the 100-year earthquake and 1 to 2 ft following the 475-year earthquake.

Based on the liquefaction assessment and slope displacement estimates, the RD is expected to have acceptable seismic performance. Anticipated settlement and displacement under the 100-year event is expected to be significantly less than proposed cap thicknesses. During a larger earthquake, the cap may move down the slope, but it is not expected to be breached.

Post-earthquake assessment mitigation measures will be identified in the Long-Term Monitoring Plan and could include visual inspections and bathymetry surveys to evaluate the condition of caps. Cap repairs, if needed, could be readily implemented by adding more cap substrate to address any local thinning associated with post-earthquake deformation or settlement.

Details of the seismic performance evaluation are presented in Appendix C.

8.4 Summary of Geotechnical Engineering Design Recommendations

Table 8-1 summarizes the key geotechnical engineering recommendations presented in this section of the BODR.

Table 8-1
Summary of Key Geotechnical Engineering Design Recommendations

Remediation Element	Geotechnical Evaluation	Conclusion
Dredging	Temporary Side Slopes	2H:1V side slopes have acceptable FOS
	Long-Term Side Slopes	3H:1V side slopes have acceptable FOS
	Recommended Structural Offset	Offset dredge cuts at least 5 ft from vertical structures
Capping	Bearing Capacity	Caps up to 4 ft thick have acceptable bearing capacity FOS
	Subgrade Settlement	Settlement of 2 to 3 inches predicted for caps in dredge and cap areas Settlement of 5 to 10 inches predicted for caps in dredge offset areas Settlement is estimated to occur within 120 days after cap placement
	Static Slope Stability	Caps at RAL exceedance area 18 have acceptable slope stability FOS
	Seismic Performance	Estimated displacement of caps under 100-year earthquake = 1 to 2 inches Estimated displacement of caps under 475-year earthquake = 1 to 2 ft
Backfill	Long-Term Side Slopes	For sand and gravel backfill, 3H:1V side slopes have acceptable FOS For armor rock backfill, 2H:1V side slopes have acceptable FOS

Notes:
FOS: Factor of Safety
RAL: remedial action level

9 Structural Engineering Considerations

Within the upper reach there are several structures and utilities that are adjacent to RAAs. Structural engineering evaluations are used to develop measures to protect or replace existing structures or utilities that may be affected during implementation of the proposed remedial actions. This section presents the results and recommendations of the structural engineering evaluations for the Preliminary (30%) RD. Structural evaluations and recommendations will be updated for Intermediate (60%) RD to reflect the geotechnical engineering recommendations presented in Section 8 and Appendix C.

Visual inspections of structures were conducted during Phase I and Phase II PDI activities. The following sections describe the structures identified within or adjacent to RAAs and structural engineering design considerations that were evaluated to develop initial recommended actions for Preliminary (30%) RD.

9.1 Structure Types

Structure types located within or adjacent to RAAs include bridges, marinas, wharves, bulkheads, piles, dolphins, timber groins, stormwater outfalls, and utility crossings. Tables 9-1 and 9-2 present these structure types relative to the respective RAA, citing RAA numbers and general riverbank locations. These tables also identify the structure types, specific facility name, and notable descriptions/features.

9.1.1 Overwater/In-Water Structures

Overwater structures consist of bulkheads, wharves, and the South Park Bridge. In-water structures include single pile fields, dolphins, and South Park Bridge bascule piers and fendering systems. Along the west riverbank, structures within or adjacent to RAAs include the South Park Marina floats and guide piles, the South Park Marina gravity block wall bulkhead, and the South Park Bridge west riverbank abutment. South of the South Park Marina, a new pile-supported pier was recently constructed as part of the improvements at T-117 EAA.

The bulkheads along the east bank include closely spaced timber soldier piles and lagging (stubs), steel sheetpiles, and steel soldier piles with a variety of lagging materials. The southern end of the east bank site area includes several rows of timber groins (closely spaced timber piles that function for river flow diversion and shoreline erosion protection). Other RAAs have structures including single creosote-treated timber piles and multi-timber pile dolphin structures. Treated timber piles are also used for some of the guide piles in the marina; other guide piles in the marina have been replaced with steel piles since the time of original construction.

With the exception of the South Park Bridge and the southern bulkhead on the Boeing Isaacson/Thompson property, the majority of existing structures evaluated within the LDW upper reach lack as-built record drawings, and the initial design and current load capacities are unknown.

Table 9-1
LDW Upper Reach Overwater/In-Water Structures Within or Adjacent to RAAs

RAA	Structure Name (ID#)[1]	Structure Type	Description	Adjacent Property	Riverbank Location
4/5, 8, 10, 11	ST02	Bridge	South Park Bridge, bascule pier and fendering system	Boeing, King County	East and West
12, 13	ST20	Marina	South Park Marina, floats and guide piles	South Park Marina	West
13	ST19	Bulkheads	Gravity block wall	South Park Marina	West
18, 22, 24, 26	ST03	Bulkheads	Steel and timber pilings	Boeing, Port of Seattle	East
23	ST17	Piles	Single timber pile field	Boeing	West
27	ST04	Dolphins	Timber piles	Container Properties	East
28	ST05	Wharves	Concrete pile supported piers and wharf	Boeing	East
29	ST07	Wharf	Timber pile supported wharf	Boeing	East
30, 31	ST10	Piles	Single timber pile field	Port of Seattle	West
32, 33, 34	ST07	Groins	Timber pile groins	Boeing	East

Notes:
1. Structure ID# corresponds to the structural field inspection forms presented in DER Appendix F.
RAA: remedial action area

There are also two identified subsurface utility crossings in the upper reach (associated with the former and current South Park Bridge). The location of these crossings is provided within the King County South Park Bridge construction as-built drawings and has been incorporated into the project basemaps. The crossing under the current South Park Bridge is an active utility line. The second crossing consists of three individual abandoned electrical lines that served the former bridge.

9.1.2 Outfalls

There are several public and privately owned stormwater outfalls and one combined sewer/stormwater outfall along the upper reach east and west riverbanks consisting of cast iron, steel, or concrete pipeline material of various sizes, physical properties, and support conditions. Some of the outfalls remain active while others have been abandoned or are inactive.

Outfalls located within RAAs on the east bank are mostly ground-supported, with some that are supported by the existing bulkhead structures. All outfalls located within RAAs on the west bank are ground-supported.

Table 9-2
LDW Upper Reach Outfall Structures Within or Adjacent to RAAs

RAA	Outfall Name (ID#)	Active or Inactive	Pipe Diameter	Pipe Material	Adjacent Property	Riverbank Location
13	2214	Active	12″	CMP	South Park Marina	West
	17th Ave SD	Active	18″	HDPE		West
18	2061	Active	24″	Steel	Boeing, Isaacson/ Thompson, Port of Seattle	East
	2062	Active	48″	CMP		East
	2063	Inactive	4″	Steel		East
22	2075	Active	32″	Steel	Centerpoint Properties	East
	2076	Inactive	30″	Steel		East
	2077	Active	21″	Steel	Boeing	East
24	2074	Inactive	8″	CMP	Centerpoint Properties	East
26	2073	Active	18″	Concrete		East
32	2097	Active	8″	Steel	Boeing	East
33	DC16	Active	6″	Ductile Iron		East
34	2096	Active	6″	Cast Iron		East
35	2093	Active	24″	Concrete		East
	2094	Inactive	12″	Concrete		East

Notes:
1. The outfall information is from the LDW Remedial Investigation and Leidos 2014 and 2020 outfall inventory surveys (Windward 2010; Leidos 2014; Leidos 2020), supplemented with information obtained during the PDI and from LDWG.

CMP: corrugated metal pipe
HDPE: high-density polyethylene
RAA: remedial action area
SD: storm drain

9.2 Structural Engineering Design Considerations

Dredging and capping can affect the integrity of structures located adjacent to the work because new loading conditions are imposed on structures. The following structural engineering design considerations are evaluated to develop the engineering design recommendations presented in Section 9.3.

9.2.1 Dredging Offsets

Dredging offsets are routinely considered in engineering design to protect existing structures and slopes, including armored slopes, that could otherwise be adversely affected by dredging activities. Preliminary offsets have been defined as described in Section 8.3.5 based on geotechnical evaluations. Further refinement to these offset distances will be made during Intermediate (60%) RD, if appropriate, based on structural evaluations.

9.2.2 Load Restrictions

Load restrictions for specific structures are considered in engineering design because the design and current load-carrying capacity for the structures is not known in most cases. The assigned load restriction must consider maintaining the estimated structural capacity and minimizing potential impacts to the structure.

Structure types that could warrant load restrictions include wharves and shoreline bulkheads. A temporary restriction on loading of the top of the structure may be required during dredging activities adjacent to the structure. Areas where load restrictions are practicable and necessary will be included in the Intermediate (60%) RD documents.

9.2.3 Temporary Shoring/Support

Temporary shoring/support is considered for a structure when a load limit is not sufficiently protective or there is a significant depth or extent of dredging required adjacent to an existing structure. Temporary shoring can also be used to protect banks where significant dredge depths may be required at the bottom of the bank.

Temporary shoring/support applies primarily to outfalls located in bank excavation areas. As discussed in Appendix C, temporary shoring may also be a component of the approach at Area 13 in the South Park Marina, depending on integration decisions between the upland and sediment cleanup projects in this area. If temporary shoring is determined necessary, details of the shoring design will be presented in Intermediate (60%) RD.

9.2.4 Overhead Structure Vertical Clearance

Overhead structure vertical clearance refers to the space needed for construction equipment to work or pass beneath a structure that spans the waterway. For example, when the South Park Bridge is in its typical position to allow street traffic to cross the river, vessel traffic passing beneath the bridge must be shorter than the posted vertical clearance. Overhead structure vertical clearance considerations are applicable at the South Park Bridge (ST02) and South 98th Street (Boeing) Bridge (ST-08) crossing, both inside and outside of the FNC. When the South Park Bridge is closed, overhead vertical clearance is posted at 29 ft. In the open position (closed to street traffic), the South Park Bridge overhead vertical clearance is 125 ft (NOAA 2017). Additionally, vertical clearance information for structures downstream from the upper reach site (e.g., 1st Avenue South Bridge, Spokane Street Swing Bridge) will be relevant information for contractor site access. Overhead structure vertical clearance information will be included on the Intermediate (60%) RD drawings.

9.2.5 Outfall Temporary Flow Diversion

Flow of active stormwater outfalls will be maintained during implementation of remediation actions; however, the existing location of an outfall may interfere with completion of remediation actions at some locations. Therefore, ground-supported outfall flows may be temporarily diverted by either pumping or rerouting the stormwater flow to another location. The design of temporary stormwater flow diversion, maintenance, and operation during construction will be the responsibility of the contractor. The design of final restoration of stormwater outfalls will be provided in Intermediate (60%) RD and will be as close as possible to the original grade and alignment, but may also include outfall extension and bank protection, as discussed in the following sections.

9.2.6 Outfall Extension

It is anticipated that the finished grade after implementation of remediation activities may not match the existing grade in certain RAL exceedance areas. Therefore, existing ground-supported outfall pipelines may need to be extended or modified to accommodate the post-construction grades and elevations. Factors that will be considered in choosing to extend an outfall pipeline include the distance between finished grade and pipe invert elevation or the discharge point. Pipe extension and coupling/connections will be designed to match existing pipeline alignment, size, and material. The Intermediate (60%) RD will provide design details for outfall extensions, where needed.

9.2.7 Outfall Bank Protection

Another structural consideration for ground-supported outfalls is to incorporate engineered bank protection measures into the design. Outfalls may be armored or supported on splash pads/aprons or other flow energy dissipator systems to protect the bank from erosion due to the outfall flow discharge. Outfall bank protection details will be presented in the Intermediate (60%) RD.

9.2.8 Temporary Relocation or Demolition and Replacement

Some in-water structures that impede or restrict access to remedial construction will be temporarily relocated or demolished and replaced. Structures identified for temporary relocation include the floats and guide piles at the South Park Marina (ST20) to allow for access to RAL exceedance area 13. Candidate structures for demolition and replacement include treated timber piles, dolphins, and timber groins. No outfall structures are currently identified for demolition and replacement.

Table 9-3 provides a summary of the protective options that are applicable to the structure types located within a RAL exceedance area. Engineering design evaluations will be completed during

Intermediate (60%) RD for each structure type. Applicable engineering design consideration and a summary of structure design recommendations are presented in Section 9.3.

Table 9-3
Structure Types and Engineering Design Considerations for LDW Upper Reach RAAs

Structure Type	Structural Considerations								RAA
	Dredging Offsets	Load Restrictions	Temporary Shoring/Support	Overhead Structure Vertical Clearance	Outfall Temporary Flow Diversion	Outfall Extension	Outfall Bank Protection	Temporary Relocation and Demolition and Replacement	
Bridges	●			●					4/5, 8, 10, 11, 32, 33, 34, 35
Marinas	●							●	12, 13
Wharves	●	●		●					28
Bulkheads	●	●							13, 18, 22, 24, 26
Timber Piles	●							●	23, 30, 31
Timber Dolphins	●							●	27
Timber Groins	●							●	32, 33, 34
Utility Crossings	●								4/5, 8
Outfalls	●		●		●	●	●		13, 18, 22, 24, 26, 32, 34, 35

Note:
RAA: remedial action area

9.3 Recommended Structural Actions

Recommended structural actions are defined as the specific structural engineering design action or requirement that will be applied during implementation of remediation activities. Each recommendation considers the condition of the structure, future use of the structure, construction cost efficiency, and maximizing the extents and environmental benefits of implementing the proposed remedial actions. The following sections summarize the recommended structural actions that have been developed for overwater/in-water structures and outfalls located within and adjacent to RAAs for the Preliminary (30%) design. These recommendations will be revisited during Intermediate (60%) RD and revised if appropriate.

9.3.1 *Overwater/In-Water Structures Recommended Actions*

Overwater/in-water structures adjacent to or within RAAs have been evaluated to develop initial recommended actions for structural protection. Table 9-4 summarizes these recommendations.

Table 9-4
Upper Reach Overwater/In-Water Structures Recommended Actions

RAA	Structure Name (ID#)	Structure Type	Description	Adjacent Property	Recommended Action[1]
4/5, 8, 10, 11	ST02	Bridge	South Park Bridge, bascule pier and fendering system	Boeing, King County	• 10 ft dredge offset from bridge and fender • Overhead clearance
12, 13	ST20	Marina	South Park Marina, floats and guide piles	South Park Marina	• Temporary float relocation and guide pile replacement
13	ST19	Bulkhead	Gravity block wall	South Park Marina	• TBD pending coordination with upland cleanup at South Park Marina
18, 22	ST03	Bulkhead	Steel and timber pilings	Boeing, Port of Seattle	• TBD pending coordination with upland cleanup at Isaacson/ Thompson (18) • 10 ft dredge offset from bulkhead
24, 26	ST03	Bulkhead	Steel sheetpile	Container Properties	• 10 ft dredge offset from bulkhead
27	ST04	Dolphins	Timber piles	Container Properties	• Demolish timber dolphins, as necessary • Replace actively used piles that were demolished
30, 31	ST10	Piles	Single timber pile field	Port of Seattle	• Demolish timber piles
32, 33, 34	ST07	Groins	Timber pile flow diversion	Boeing	• Demolish and replace timber groins

Notes:
1. Individual structures will be assessed during Intermediate (60%) RD to update recommended actions.
RAA: remedial action area
TBD: to be determined

9.3.2 *Outfall Recommended Actions*

Outfalls located within or adjacent to RAAs have been evaluated to develop initial recommendation actions for dredging setbacks/offsets, temporary shoring/support, temporary outfall flow diversion, outfall extension, and bank protection. Table 9-5 presents recommended actions as they apply to the outfall structures.

Table 9-5
LDW Upper Reach Outfall Structures Recommendation Actions

RAA	Outfall Name (ID#)	Active or Inactive	Pipe Diameter	Pipe Material	Recommended Action
13	2214	Active	12″	CMP	• Confirm location in Phase III PDI • Outfall bank protection
13	17th Ave SD	Active	18″	HDPE	• Confirm location in Phase III PDI
18	2061	Active	24″	Steel	• Protect using measures developed during Intermediate (60%) RD
18	2062	Active	48″	CMP	• Protect using measures developed during Intermediate (60%) RD
18	2063	Inactive	4″	Steel	• Demolish
22	2075	Active	32″	Steel	• Temporary shoring/support • Outfall extension
22	2076	Inactive	30″	Steel	• Demolish
22	2077	Active	21″	Steel	• Temporary shoring/support
24	2074	Inactive	8″	CMP	• Demolish
26	2073	Active	18″	Concrete	• Temporary shoring/support
32	2097	Active	8″	Steel	• Coordinate with Boeing on timing for storm drain system modifications • Confirm location in Phase III PDI if needed
33	DC16	Active	6″	Ductile Iron	• Coordinate with Boeing on timing for storm drain system modifications • Confirm location in Phase III PDI
34	2096	Active	6″	Cast Iron	• Coordinate with Boeing on timing for storm drain system modifications • Confirm location in Phase III PDI
35	2093	Active	24″	Concrete	• Coordinate with Boeing on timing for storm drain system modifications • Temporary shoring/support • Outfall bank protection
35	2094	Inactive	12″	Concrete	• Coordinate with Boeing on timing for storm drain system modifications • Demolish

Notes:
1. The outfall information is from the LDW Remedial Investigation and Leidos 2014 and 2020 outfall inventory surveys (Windward 2010; Leidos 2014; Leidos 2020), supplemented with information obtained during the PDI and from LDWG.

CMP: corrugated metal pipe
HDPE: high-density polyethylene
PDI: pre-design investigation
RAA: remedial action area
SD: storm drain

10 Remedial Technology Design

This section describes the development of design criteria for the selected RD elements summarized in Section 2.1.2. The criteria described in this section will be incorporated into the specifications during Intermediate (60%) RD. This section also describes the design analyses conducted to select the criteria, including a summary and detailed description of objectives, design assumptions, and restrictions (where appropriate) that are used in the design of the remedial actions. Specifically, details are provided for the following:

- Equipment Selection
- Dredge Design
- Engineered Cap Design
- ENR Design
- Material Types and Placement Methods
- MNR
- Flood Rise Analysis
- Maintenance, Monitoring, and Institutional Controls

Application of the criteria is demonstrated on the Preliminary Drawings, included as Appendix D. Details of implementing these criteria will be provided in the specifications, which are provided in outline form at Preliminary (30%) RD in Appendix E and will be further developed during Intermediate (60%) RD.

10.1 Equipment Selection

Equipment selection for sediment remediation projects must be carefully considered by contractors using their experience with the site conditions, standard and specialized equipment they have used and have access to, and the expertise of their personnel. Equipment selection is typically based on the ability of the equipment and contractor means and methods to meet performance-based specifications that require a minimum performance to be achieved by the contractor. These performance specifications include specified tolerances, environmental criteria (e.g., water quality), production rate, health and safety, accuracy, and quality of life considerations (e.g., air, noise, and light).

Using performance specifications allows experienced remediation contractors to develop the appropriate means and methods for using equipment that they determine is the most appropriate for the different site conditions they will encounter in the upper reach. Performance-based design approaches are key lessons learned from previous EAAs (see Table 2-2 of the RDWP). Performance-based specifications inform the operational characteristics and requirements of the project design and allow for contractor expertise, use of specialized equipment, and contractor flexibility to perform the work based on the constraints of the design and unique site characteristics.

The design approach to inform the contractor's equipment selection will be a combination of performance-based specifications with some use of method-based specifications, which are specifications that direct the contractor to conduct specific work in a specific manner. An example of a performance specification will be to set the water quality criteria that the contractor will be required to meet during in-water operations, but not tell the contractor what equipment to use to meet that performance criterion. An example of a method specification is to tell the contractor to dredge a side slope from the top of the cut slope to bottom of the cut slope to limit the risk of slope failure.

Requiring a contractor to use a specific piece of equipment or method (e.g., method specifications) can ultimately be limiting and may prevent the contractor from applying their experience on how to best accomplish the dredging work while meeting environmental performance criteria. In this sense, using only method specifications can have the unintended consequence of a dredging project that is less environmentally protective than a project where the contractor can choose the equipment and bring their experience to bear. Thus, for this project, remediation equipment selection will be done by the contractor to meet performance specifications that dictate the required environmental outcomes, the monitoring that will be conducted, and the contingency actions that will be taken to improve environmental protectiveness.

The contractor will identify proposed equipment in the Remedial Action Work Plan (RAWP), subject to review and approval by the Implementing Entity and EPA. A well-planned quality assurance (QA)/quality control (QC) program will be detailed in the CQAP and reflected in the project specifications, to confirm the work identified in the specifications, design drawings, and RAWP are being measured and met as construction proceeds. The contractor will be required to modify procedures and equipment as needed to meet the performance specifications.

Based on past experience, the following sections include discussion of the specific equipment that is anticipated to be used by the contractor.

10.2 Dredge Design

This section documents the basis for dredging equipment selection and describes the dredge prism design criteria, dredging tolerances, and anticipated dredging production rates. Additionally, this section describes support activities associated with dredging, including material transloading, upland transport and disposal, post-dredge sampling, dredge residuals management, and post-dredge backfilling.

10.2.1 Dredging Equipment Selection

The FS included screening of removal process options, including mechanical dredging methods (e.g., mechanical cranes and barge-mounted excavators), hydraulic dredging methods, and upland excavation. The FS discusses the infeasibility for using hydraulic dredging as the primary dredge method due to impacts to waterway users, lack of upland space to dewater hydraulically dredged slurry, inability to remove debris, and other site constraints within the LDW. Hydraulic dredging entrains significant amounts of additional water (e.g., typically four to seven times the volume of dredged sediment), which requires a large area for dewatering and water treatment processes, increases the energy used, adds complexity, and generates additional waste streams (e.g., process water, expended treatment media). Hydraulic dredging also transports the dredged materials as a slurry through a hydraulic transport pipeline that extends from the hydraulic dredge to the dewatering site, sometimes located miles away; these transport pipelines are typically floating and obstruct the use of the waterway where the pipeline is located. Hydraulic dredging had been retained in the FS for location-specific circumstances where the total amount of water generated would be small and controllable. Evaluation during the Preliminary (30%) RD has determined that hydraulic dredging will not be required for the upper reach.

Mechanical dredging and excavation are the most commonly practiced forms of sediment removal in the Puget Sound region, with approximately 90% of projects in the region using it during project implementation. These methods are adopted in the Preliminary (30%) RD as the primary removal equipment for in-water work. Mechanical dredging is expected to be the optimal method in open-water areas because of its effective removal of consolidated sediment, debris, and other materials such as piling and riprap; and its relatively compact operational footprint, thus reducing the potential impact to existing waterway operations. Dry excavation using conventional earth-moving equipment working above the water line is also retained for use in intertidal and embankment areas, but it is expected to be implementable only for a low percentage of the removal volume because of access limitations.

10.2.1.1 Mechanical Dredging Equipment and Bucket Selection

Mechanical dredges employ a bucket to retrieve sediment from the bed of the waterway, move the sediment up through the water column, and place it into an adjacent haul vessel (such as a barge) for transport and disposal. Two major categories of mechanical dredges are differentiated based on the method of bucket deployment. The first category uses a wire attached to a crane or derrick to lower the bucket to the bed and retrieve sediment. The second category deploys the bucket at the end of the arm of an excavator or backhoe and is sometimes referred to as an articulated fixed-arm dredge. Mechanical dredges can be further classified by the type of bucket used, such as conventional open clamshell bucket or environmental buckets (Exhibit 10-1). The Technical Guidelines for Environmental Dredging of Contaminated Sediments (USACE 2008a) described the following types of mechanical dredge buckets:

- **Conventional Clamshell Bucket:** This conventional dredge consists of a wire-supported, open clamshell bucket. This bucket is often used from a barge-mounted derrick crane and is a heavy bucket with teeth that are suitable for digging consolidated materials, handling debris, and penetrating deeply into sediment to allow higher production rates.

- **Environmental Bucket:** The environmental (aka, closed) bucket is a near watertight or sealed bucket (when complete bucket closure is possible) as compared to the conventional open bucket. Recent designs (e.g., Cable Arm) also incorporate a level-cut capability as compared to a circular-shaped cut for conventional buckets. The environmental bucket is typically lighter in weight than conventional clamshell bucket and can be ineffective when dredging consolidated sediment, rock, or debris.
- **Articulated Bucket:** Articulated buckets include both conventional buckets and environmental buckets but use a hydraulic closing mechanism to operate the bucket instead of a cable or wire pulley system. The articulated bucket is typically supported by an articulated, fixed arm (for example Hydraulic Profiling Grab bucket system, Young Manufacturing rehandling bucket). Articulated buckets may have tighter control on bucket location than a bucket suspended on a cable or wire pulley system. Articulated buckets used for sediment remediation dredging are typically 3 to 6 cy in size and are fully closing.

Because of their "closed" design, environmental buckets can result in capturing more water than a standard digging bucket, requiring the design to anticipate a larger volume of water (than standard digging buckets) that will need to be managed, and increasing the dissolved phase contaminant releases. The closed design also creates large bow wakes as they dig into the sediment and expels sediment out its sides as it closes, which resuspends more sediment and generates residuals. During precision environmental dredging projects, the dredging bucket may be only half-full of sediment on average over the course of the project due to relatively thin cuts intended to avoid removal of non-impacted sediment and to avoid over-penetration of the bucket, with water filling the other half of the bucket. The volume of water placed in the barges for an environmental dredging project can therefore equal the volume of sediment dredged from the upper reach. The water management associated with articulated environmental buckets with closing mechanisms can therefore be a significant volume (e.g. 100,000 cy sediment dredged equals 100,000 cy, or 17.4 million gallons, of dredge return water). The fixed-arm nature of this type of dredging equipment limits the reach and depth that it may be capable of dredging but this limitation is not anticipated to be a significant factor in the upper reach.

Exhibit 10-1
Different Bucket Types

Conventional clamshell bucket

Environmental bucket

Articulated bucket (Horizontal Profile Grab)

Environmental buckets have been designed to work with mechanical dredging equipment (e.g., derrick cranes or hydraulic excavators). However, minimizing the loss of sediment out of the bucket does not necessarily mean reducing suspended solids or lowering turbidity. As discussed in Wang et al. (2002), environmental buckets have not been proven to reduce suspended sediments in all site conditions. For example, in site conditions with significant debris, environmental buckets may not be able to fully close and tend to lose most or all of the dredged sediment from the bucket as it is raised through the water column. A standard clamshell digging bucket will be more effective at removing debris or dense substrate and be able to close tighter to prevent loss of dredged sediment. Environmental buckets are also typically lightweight in construction and typically not suitable for digging denser or consolidated sediments, requiring multiple passes to remove the material or being ineffective at achieving the required dredge elevations and grades. When used in unconsolidated sediments without significant debris, environmental buckets have been shown to be effective at reducing loss of sediment from the bucket.

The selection of dredge bucket and equipment is project- and contractor-specific and can vary depending on location-specific factors even for a single dredging project. The best equipment for one task may be unsuitable for another task. Dredging soft sediments in open water with minimal debris can be effectively accomplished with a conventional derrick crane and environmental and closed buckets, although the more closed the bucket is, the more sediment is expelled out the sides into the water column as it closes. Constrained dredging in limited access areas may be more appropriately accomplished using an articulated bucket. When using enclosed environmental buckets (either wire-supported or fixed arm), debris can limit the efficiency of sediment removal by preventing the bucket from fully closing, which will unavoidably increase dredging residuals and negate the benefits of the enclosed bucket.

While the contractor will ultimately select the appropriate equipment for dredging, it is anticipated that a 6- to 8-cy sized dredge bucket would reasonably be used for dredging in most locations given the size of the project and requirements for bank dredging. The contractor will be required to have an environmental-type closing bucket available, recognizing that sloping cuts and bank areas may be conditions not suitable for an environmental bucket. In areas that contain small to larger debris (e.g., heavy vegetation, rock and concrete slabs, intact and broken pilings, and fused debris piles) or harder sediment, environmental buckets are anticipated to be ineffective because debris limits the ability of an environmental bucket to penetrate the subgrade; therefore, a heavier bucket with conventional digging capabilities or a specialized bucket to remove debris would likely be the type of equipment selected by the contractor.

Land-based excavation using excavators, backhoes, and other conventional earth moving equipment may be used to remove intertidal and bank area materials. Excavation in these areas may be coordinated "in the dry" during periods of low tidal elevations; however, depending on weather, tides, scheduling, and contractor production, it will be necessary to conduct some intertidal excavation below water. Given the geometry of the bank areas and the typical reach of upland-based equipment, it is anticipated that materials removed from the bank areas may need to be placed into a temporary upland stockpile area or directly into trucks depending on site access agreements and available upland space. Thus, any land-based work will require access, staging areas, loading operations, and ground transportation. These logistical factors tend to favor accomplishing the work with floating equipment.

Excavation and dredging operations have well-established BMPs to limit sediment disturbance and manage potential water quality impacts (USACE 2008a). Operational and engineering controls will be defined in the construction specifications and the project permits, which the contractor will be required to implement. A list of construction BMPs related to mechanical dredging and reducing water quality impacts during dredging is discussed in Sections 11.1 and 11.2.

10.2.2 Dredge Prism Design

As described in Section 6, horizontal limits of the RAAs were set to encompass the RAL exceedance area, and modified to account for engineering considerations, review of adjacent chemistry results, and constructability considerations. Vertical extent of contamination was defined on either an elevation or thickness basis to remove material exceeding the surface RALs (0-10 cm [0 to 4 inch]). The dredge prism design combines these considerations to target removal of the horizontal and vertical extents of contamination.

Dredge elevations were used as the basis for the vertical extent of dredging when data suggest similar elevations of contamination. In general, this occurs in areas within the FNC and existing berthing areas due to the typical nature of past dredging to constant dredge elevations in these areas (suggesting contaminant releases would have been expected to settle above a similar elevation). For elevation-based dredge prisms, core data were reviewed to establish the deepest extent of contamination, which was then rounded to the next deepest half-foot interval. For example, if the bottom of the deepest core interval exceeding surface RALs was at -18.3 ft MLLW, the required dredge elevation was set to -18.5 ft MLLW. If the deepest exceeding core interval was at -18.0 ft MLLW, the required dredge elevation was set to -18.5 ft MLLW.

Dredge thickness cuts were used as the basis for the vertical extent of dredging when vertical core data suggested similar thicknesses of contamination within an area. This approach generally occurred in areas outside the FNC and in areas that are present along slopes. Thickness cuts were also assigned to some areas within the FNC or berthing areas with vertically bounded contamination with only RAL exceedances in the 0-10 cm (0-4 inch) or 0-60 cm (0-2 ft) intervals. For these areas, the vertical extent of dredging was assigned a minimum dredge thickness because the data indicate that contamination is found only on the upper surface of the sediment bed at that location. Dredge thicknesses were defined by the depth of contamination, using the interface between the core interval that exceeded the surface RALs and the core interval that was below the surface RALs. For example, at a location with a 0-45 cm (0-1.5 ft) RAL exceedance and the next two 1-ft core intervals exceed the surface RALs, but the next 1-ft core interval does not exceed the surface RALs, the dredge thickness was set at 3.5 ft. In contrast to elevation-based dredge depth locations, extra depth was not added to thickness cuts because the thickness cut is already delineated to constructible 0.5-ft intervals. In addition, the core compaction correction process that was used during the PDI effectively "expands" the thickness of the RAL exceedance interval, which results in a conservative estimate of thickness. Surface-only RAL exceedances (i.e., 0-10 cm [0-4 inches]) were assigned a required dredge thickness cut of 1 ft to account for constructability considerations.

RAAs with multiple cores may have had different assigned vertical contamination elevations or thicknesses and were therefore broken into subareas, with each subarea having a different required dredging elevation or thickness. These subareas are notated with a letter following the RAA label (e.g., Area 2/3A vs. 2/3B). RAA subareas are shown on the Preliminary Drawings (Appendix D). Table 10-1 summarizes the vertical dredge prism design basis for each RAA or RAA subarea.

Table 10-1
Dredge Prism Vertical Design by RAA

RAA	Elevation or Depth of Contamination Based on Vertical PDI Data Within RAA	Basis of Dredge Elevation/Thickness	Required Dredge Elevation/ Thickness
1	510 unbounded at -17.6 ft MLLW	Depth of contamination assumed using nearest core, 509, which is bounded at -21.2 ft MLLW	-21.5 ft MLLW
2/3A	509 bounded at -21.2 ft MLLW	-21.2 ft MLLW	-21.5 ft MLLW
2/3B	514 bounded at -20.5 ft MLLW 517 bounded at -20.8 ft MLLW 519 unbounded at -17.2 ft MLLW 520 bounded at -20.4 ft MLLW	-20.8 ft MLLW	-21 ft MLLW
2/3C	521 bounded at -19.9 ft MLLW	-19.9 ft MLLW	-20 ft MLLW
4/5A	527 bounded at -20.3 ft MLLW	-20.3 ft MLLW	-20.5 ft MLLW
4/5B	529 bounded at -18.5 ft MLLW	-18.5 ft MLLW	-19 ft MLLW
4/5C	531 bounded at -21.2 ft MLLW	-21.2 ft MLLW	-21.5 ft MLLW
4/5D	532 bounded at -20.4 ft MLLW 533 bounded at -20.2 ft MLLW	-20.4 ft MLLW	-20.5 ft MLLW
4/5E	534 bounded at -21.4 ft MLLW	-21.4 ft MLLW	-21.5 ft MLLW
4/5F	535 bounded at -21.6 ft MLLW	-21.6 ft MLLW	-22 ft MLLW
4/5G	537 bounded at -20.7 ft MLLW	-20.7 ft MLLW	-21 ft MLLW
4/5H	538 bounded at -21.9 ft MLLW	-21.9 ft MLLW	-22 ft MLLW

RAA	Elevation or Depth of Contamination Based on Vertical PDI Data Within RAA	Basis of Dredge Elevation/Thickness	Required Dredge Elevation/ Thickness
4/5I	539 bounded at -20.9 ft MLLW 553 has no interval > surface RAL	-21 ft MLLW, but this would not result in the necessary removal of the subsurface RAL interval (0-60 cm [0-2 ft]) over the whole area; Therefore, a 2-ft thickness cut used instead	2-ft cut
6	No data	Interpolation only area based on subsurface (0-60 cm [0-2 ft]) RAL assumed for Preliminary (30%) RD	2-ft cut
8	N/A; area is based on surface-only exceedances; nearest subsurface sample, IT543, did not exceed RALs	Surface (0-10 cm [0-4 inch]) RAL interval exceedance (SS145)	1-ft cut
11	SC148 unbounded at -17 ft MLLW due to coring refusal on hard layer assumed to represent native alluvium layer	The bottom of core is assumed to be the contact between contaminated and clean material on the basis of coring refusal, which is a line of evidence native sediments exist below the coring depth	-17.5 ft MLLW
12	N/A; area is based on surface-only exceedances; subsurface sample SC155 did not exceed RALs	Surface (0-10 cm [0-4 inch]) RAL interval exceedance (SS155)	1-ft cut
13A	560 bounded at -8.9 ft MLLW	-8.9 ft MLLW	-9 ft MLLW
14	568 bounded at -24.4 ft MLLW	-24.4 ft MLLW	-24.5 ft MLLW
15/16	571 has no interval > surface RAL T-117-SE-35-SC core bounded at 8-ft depth	8-ft depth	8-ft cut
17	N/A; area is based on surface-only exceedances; subsurface samples SC213 and SC576 do not exceed RALs	Surface (0-10 cm [0-4 inch]) RAL interval exceedance (SS213, LTR-20-2018)	1-ft cut
18A	581 has no interval > surface RAL 582 unbounded at 6.5-ft depth 584 has no interval > surface RAL 585 unbounded at 6.5-ft depth	581 and 584 were not analyzed for arsenic and therefore might not be bounded as noted; Depth of contamination assumed to be 3 ft below unbounded core for Preliminary (30%) RD	9.5-ft cut
18B	587 bounded at 6-ft depth 588 bounded at 5.5-ft depth	6-ft depth	6-ft cut
18C	591 has no interval > surface RAL 592 bounded at 3-ft depth	3-ft depth	3-ft cut
18D	597 bounded at 3.5-ft depth	3.5-ft depth	3.5-ft cut
18E	593 has no interval > surface RAL 598 bounded at 2.5-ft depth	2.5-ft depth	2.5-ft cut

RAA	Elevation or Depth of Contamination Based on Vertical PDI Data Within RAA	Basis of Dredge Elevation/Thickness	Required Dredge Elevation/ Thickness
18F	N/A; area is based on surface-only exceedances; subsurface sample SC600 did not exceed RALs	Surface (0-10 cm [0-4 inch]) RAL interval exceedance (SS600)	1-ft cut
19/20A	No vertical data	Subsurface (0-45 cm [0-1.5 ft]) RAL interval exceedance (IT606)	1.5-ft cut
19/20B	609 bounded at 3.5-ft depth	3.5-ft depth	3.5-ft cut
21	No data	Interpolation only area based on subsurface (0-60 cm [0-2 ft]) RAL assumed for Preliminary (30%) RD	2-ft cut
22	621 has no interval > surface RAL 622 bounded at 2-ft depth	2-ft depth	2-ft cut
24	632 bounded at 3.5-ft depth	3.5-ft depth	3.5-ft cut
26	644 has no interval > surface RAL	Surface (0-10 cm [0-4 inch]) RAL interval exceedance at multiple sample locations	1-ft cut
27A	648 bounded at 4.5-ft depth 653 bounded at 3.5-ft depth	4.5-ft depth	4.5-ft cut
27B	649 bounded at 2.5-ft depth 650 has no interval > surface RAL 652 bounded at 2.5-ft depth 654 bounded at 2.5-ft depth 655 has no interval > surface RAL 657 has no interval > surface RAL 658 bounded at 2.5-ft depth 659 bounded at 2.5-ft depth 660 bounded at 2.5-ft depth	2.5-ft depth	2.5-ft cut
27C	662 bounded at 2.5-ft depth 663 bounded at 3.5-ft depth 664 bounded at 2.5-ft depth 665 bounded at 3.5-ft depth 666 bounded at 3.5-ft depth	3.5-ft depth	3.5-ft cut
28	674 has no interval > surface RAL	Subsurface (0-60 cm [0-2 ft]) RAL interval exceedance (SC349, SC671)	2-ft cut
29	683 has no interval > surface RAL 684 has no interval > surface RAL	Subsurface (0-45 cm [0-1.5 ft]) RAL interval exceedance (IT379)	1.5-ft cut
30	694 bounded at 1.5-ft depth	1.5-ft depth	1.5-ft cut
31	No vertical data	Subsurface (0-45 cm [0-1.5 ft]) RAL interval exceedance (IT697)	2-ft cut
32	Surface RAL exceedance (0-10 cm [0-4 inch])	Surface (0-10 cm [0-4 inch]) RAL interval exceedance at multiple sample locations	1-ft cut
34	Surface RAL exceedance (0-10 cm [0-4 inch])	Surface (0-10 cm [0-4 inch]) RAL interval exceedance at multiple sample locations	1-ft cut

RAA	Elevation or Depth of Contamination Based on Vertical PDI Data Within RAA	Basis of Dredge Elevation/Thickness	Required Dredge Elevation/ Thickness
35	701 and 702Y have no interval > surface RAL	Surface (0-10 cm [0-4 inch]) RAL interval exceedance at multiple sample locations	1-ft cut

Notes:
MLLW: mean lower low water
N/A: not applicable
PDI: pre-design investigation
RAA: remedial action area
RAL: remedial action level
RD: remedial design

10.2.2.1 Dredge Cut Side Slopes

Dredge cut side slopes were evaluated as described in Section 8 by identifying typical side slope angles and computing the factor of safety for the dredge cut slope under both short-term conditions (prior to backfilling) and long-term conditions (post-construction). Based on these evaluations, it was determined that dredge cut side slopes of 3H:1V should be used to maintain an adequate factor of safety for the long-term condition, while dredge cut side slopes of 2H:1V are allowable for the short-term condition.

Internal slopes between dredge units are assumed to be cut at 2H:1V, with the toe of the slope set at the deepest elevation or depth along the interface of the units.

10.2.2.2 Horizontal Dredge Offsets

Section 9 identifies the in-water and shoreline structures that are within or adjacent to an RAA, including structures that will be protected in place and structures that will be removed (and potentially replaced). The Preliminary (30%) RD dredge design includes horizontal offset requirements for structures based on adjacent required sediment removal elevations/thickness cuts and associated short-term and long-term structure stability. These dredging offset distances will be further evaluated and specified in Intermediate (60%) RD.

Offset recommendations for structures have been summarized in Section 8 and are shown on the Preliminary Drawings. For Preliminary (30%) RD, no horizontal offsets have been assumed for outfalls. The Intermediate (60%) RD will evaluate design details for protection of each affected outfall.

10.2.3 Dredging Tolerances

The dredge prism includes two components: the required dredge elevation/thickness and the allowable overdredge tolerance. The required dredge elevation/thickness information provided in Table 10-1 represents the removal elevation grades or thickness that a contractor will be required to remove all sediment above throughout the RAA subarea. To achieve the required dredge elevation/thickness, an allowable overdredge tolerance, which is an additional depth of sediment below the required dredge elevation/thickness that may be removed, is necessary to account for dredging equipment accuracy, operator skill, and site conditions. The dredge prism design (including allowable overdredge tolerance) reflects the fact that it is not possible/practical for any dredge to excavate to an exactly flat surface.

The contractor will be provided with an allowable overdredge tolerance of 1 ft below the required dredge elevation/thickness.

10.2.4 Dredging Production Rates

Dredging production rates (i.e., the volume of in situ dredged material removed on an hourly or daily basis) will vary based on the contractor's selected equipment and personnel experience, sediment physical characteristics, transport rate of dredged material to landfills, and site constraints, such as nearby vessel traffic and weather conditions. Production rates may be higher in some areas of the upper reach and lower in others, depending on the constraints affecting production including sediment type (e.g., consolidated vs. unconsolidated), water depths, cut thickness, type of cut (e.g., sloped cut), water quality protection, and presence of debris. Typically, production rates are lower at the start of new construction activities (e.g., beginning of a construction season, or start of a new activity), and then increase over time as the contractor works out efficient methods to accomplish the work. However, weather or access delays, equipment maintenance, and tangential factors (e.g., offload facility production rate) are expected to periodically slow production over relatively short time spans during a typical construction season.

It is estimated that a reasonable mechanical dredging production rate in the upper reach will be approximately 1,200 cy per day in open-water areas, such as the FNC. Dredging production rates are anticipated to be lower for contingency re-dredging, nearshore dredging, and restricted access dredging, which are estimated to range from approximately 500 cy to 900 cy per day, with an overall site-wide weighted average production rate of 1,000 cy per day. This production rate closely mirrors historic production rates for regional remediation dredging in Puget Sound and is also aligned with anticipated typical daily transloading and dredged material transportation and disposal rates. The production rates developed as part of the Preliminary (30%) RD are higher than the range of production rates presented in the FS (AECOM 2012; ranged from 277 to 781 cy/day), which results in a shorter overall project duration. Production rates will be further evaluated in Intermediate (60%) RD.

To illustrate the calculation to determine a production rate in one site condition, the anticipated daily site-wide weighted average dredging production rate is calculated using the following assumptions:

- Assume contractor uses a mechanical barge-mounted derrick crane.
- Assume derrick crane uses an 8-cy bucket.
- Assume bucket fill factor of 70% (30% of bucket is not filled with sediment).

- Assume dredge cycle time (i.e., one cycle equals the time to lower the bucket to the bottom, close the bucket with dredged material, raise the bucket out of the water, place the dredged material into the barge, and make ready for the next cycle) of 2.2 minutes per cycle.
- Assume contractor works one 10-hour shift per day (i.e., 600 minutes per day).
- Assume average operational "uptime" is 65%. Uptime is the proportion of time that the dredge is actually working. The remainder of the time (i.e., downtime) includes time for maintenance, dredge re-positioning, debris management, shift changes, time needed to periodically switch out the barges used to transport dredged material, inherent delays, and other non-dredging work.

Overall Site-Wide Weighted Average Mechanical Dredging Daily Production Rate Equation:

*Production Rate = (bucket size * bucket fill factor) *((total work minutes per day/cycle time in minutes)*%uptime))*

*= (8 cy * 70%) *((600 min/2.2 min) *65%)*

= (1,000 cy/day)

It is expected that the calculated site-wide weighted average production rate described above will vary significantly on a daily basis (both lower and higher) due to factors such as location, weather, adjacent marine traffic, the project's required environmental controls (such as turbidity control requirements, and environmental and water quality monitoring), confirmational sampling, and the resulting potential need to re-dredge some areas. However, from a schedule planning perspective, an overall site-wide weighted average rate of 1,000 cy/day was assumed to develop the Preliminary (30%) RD construction duration, with a potential range of 500 to 1,200 cy/day depending upon site conditions. Multiple dredges working simultaneously could potentially increase this daily rate. However, the constraint of offloading and shipment to a commercial landfill is anticipated to govern the maximum amount of material that can be dredged per day. Landfill and rail capacity will be further explored during Intermediate (60%) RD.

10.2.5 Transload Facilities

Sediment and debris removed from the upper reach will be loaded onto barges, or directly into trucks during upland excavation activities, and transported to a transload facility where the material will be offloaded from barges and loaded onto trucks and/or rail cars for transportation to a permitted disposal facility. Dewatering of the dredged materials for transport purposes may be performed at the transload facility if determined necessary by the disposal facility. Any effluent generated by dewatering at the transload facility will be managed (contained and, if necessary, treated) and disposed of in accordance with facility permits or authorizations for wastewater disposal.

10.2.5.1 Commercial Transload Facilities

The Duwamish Reload Facility at 7400 8th Avenue South, operated by Waste Management, is a transload facility located on the LDW. The facility has water access in Slip 4, at approximately RM 2.8.The facility has the capability to offload bulk material from barges and load onto trucks or rail cars, and it accepts nonhazardous contaminated soil and special wastes.

Lafarge North America operates a transload facility at 5400 W. Marginal Way that has water access at approximately RM 1.0 of the LDW. The facility has the capability to offload bulk material from barges, stabilize sediment, and load onto trucks or rail cars, and it accepts nonhazardous contaminated soil and special wastes.

The two facilities described above are known to be operating at the time of this Preliminary (30%) RD. Other commercial transload facilities may become available or be identified prior to construction, and the selection of a facility will be made by the contractor subject to approval by the Implementing Entity and EPA.

10.2.5.2 Contractor-Provided Transload Facility

A contractor-provided transload facility may be proposed during the contractor's work plan development phase (i.e., contractor's RAWP). The contractor would be required to obtain all necessary permits or substantive equivalence (e.g., solid waste and discharge permits) and the use of a contractor-provided transload facility would be subject to approval by the Implementing Entity and EPA.

10.2.5.3 Project-Specific Transload Facility

The design team evaluated potential locations for siting a project-specific transload facility. Given the presence of established commercial transload facilities in close proximity to the upper reach, a project-specific facility would need to offer significant advantages to offset the cost and time required to acquire or lease property, obtain necessary solid waste and discharge permits, and to develop, equip, and staff the facility. The process for evaluating potential project-specific transload facilities began with identifying criteria for the evaluation and reviewing the local real estate market to identify any that met the criteria.

The property would need certain attributes, including the following, to be considered as a potential candidate as a transload facility:

- Located on the water, ideally adjacent to the upper reach
- Have a dock with space for at least one barge
- Have rail and road access
- Located in an industrial or commercial setting without restrictions that would limit 24-hour operations

- Have sufficient size to dewater and stockpile sediment and load processed material into trucks or rail cars
- Have sufficient size to treat dewatered wastewater or pretreat and have sewer connection with adequate capacity to convey.

The review of available properties found that there are no vacant sites on the LDW for sale or lease. The nearest vacant property is two blocks from the water and therefore unsuitable for this purpose, not having water access. One developed property is for sale on the water, but a 60,000-sq-ft building that is currently occupied takes up more than half the property. Considering the lack of a suitable property, the expense of acquiring and developing the property as a transload facility, the time required to obtain necessary permits or approvals, and the availability of commercial transload capacity adjacent to the site, a project-specific transload facility is not likely to support transloading for the upper reach. Although the 30% costs assume commercial transload, the project-specific transload option has not been ruled out.

10.2.6 Upland Transport and Disposal

Disposal of dredged and excavated materials will be at a permitted landfill. Waste characterization results and acceptable landfills are discussed in this section.

10.2.6.1 Waste Characterization Results

Characterization of potential waste material (i.e., dredged material) provides preliminary data about whether the material meets both regulatory requirements and bulk chemistry and leachate concentration requirements for disposal at specific commercial landfill facilities. This characterization requires a subset of the design dataset that includes samples from within dredge areas. Because dredge areas are being developed during Preliminary (30%) RD, waste characterization evaluation will occur at the Intermediate (60%) RD phase. Based on past experience with remedial dredging on the Duwamish River, it is anticipated that materials dredged from the upper reach will be acceptable for disposal at a Subtitle D landfill. If materials are characterized as hazardous, or hazardous materials are encountered during construction, hazardous materials will be disposed of at a Subtitle C landfill.

10.2.6.2 Acceptable Landfills

Several permitted landfills in the Pacific Northwest are approved to dispose of nonhazardous contaminated sediment from Superfund sites. These include the Roosevelt Regional Landfill (owned and operated by Republic Services in Roosevelt, Washington) and the Columbia Ridge Landfill (owned and operated by Waste Management in Arlington, Oregon). Other landfills are also approved for this waste stream; acceptability criteria vary by facility. The selection of a landfill will be made by the construction contractor subject to approval by the Implementing Entity and EPA. The compliance status of the landfill will be confirmed prior to removing waste from the site in conformance with the Off-Site Rule (40 CFR 300.440). The method of transportation (i.e., truck or rail) may depend on the choice of landfill. Both the Republic Services and Columbia Ridge Landfills are served by rail. In addition, both landfills have exclusions from the requirements of the Paint Filter Test for dredge material, allowing wet material to be delivered to the landfill.

The ROD anticipated, based on RI/FS data, that material removed from the upper reach will be characterized as nonhazardous waste and not regulated by the Toxic Substances Control Act. Following the waste characterization evaluation to be completed during Intermediate (60%) RD, a list of acceptable landfills will be provided in the Intermediate (60%) RD BODR. Based on a review of the design dataset results, the Roosevelt Regional Landfill (owned and operated by Republic Services in Roosevelt, Washington) and the Columbia Ridge Landfill (owned and operated by WM in Arlington, Oregon) are anticipated to be acceptable Subtitle D landfills. In the event that hazardous materials are encountered, any of these removed materials would need to be appropriately segregated from Subtitle D materials. The nearest regional Subtitle C landfill is the Chemical Waste Management Northwest Landfill located in Arlington, Oregon. The contractor may also propose other landfills subject to approval by EPA.

10.2.7 Post-Dredge Elevation and Chemical Verification

The completeness of dredging will be verified as described in the CQAP (Summary Table, Appendix F), which will be prepared as an Intermediate (60%) RD submittal. Progress surveys will verify that the required dredge elevations or thicknesses have been met. In locations where the required dredge elevation/thickness requirements have not been achieved, the contractor will be required to remove additional material to comply with the plans and specification requirements as described in the CQAP.

Once post-dredge elevation requirements are achieved, post-dredge confirmation sampling will occur to characterize the post-dredge surface as described in the CQAP. Based on the results, contingency actions (placement of residuals management cover [RMC], re-dredging, or backfill) may be required.

10.2.8 Residuals Management Approach

Dredging residuals are unavoidable and occur with all types of dredging. The quantity and quality of dredge residuals vary depending on the dredge material properties, presence of debris, and other factors. The residuals management approach differentiates generated residuals from missed inventory.

- Generated residuals refer to the thin layer of disturbed contaminated sediment that remains on the post-dredge surface due to material loss during dredging, or due to the inability of the dredge to fully remove the material disturbed during the excavation process.

- Missed inventory refers to unanticipated contaminated sediment left undredged below the required dredging elevation/thickness that was not included in the original dredge prism design (i.e., contaminated sediment located deeper than expected).

The purpose of residuals management is to provide a clean post-remedial action surface condition whose concentrations are all below surface RALs. Residuals can occur within the dredge prism, and in adjacent sediments. The CQAP will include sampling protocols for both.

Placing RMC has provided greater certainty in achieving residual performance standards in the case study project sites evaluated in Desrosiers and Patmont (2009) and the USACE technical guidance *The Four R's of Environmental Dredging: Resuspension, Release, Residual, and Risk* USACE 2008b). The RMC is typically a relatively thin layer (e.g., average 15 cm [6 inches] and a minimum 10 cm [4 inches]) of clean sand from local commercial aggregate suppliers.

RMC is regularly used to manage thin deposits of generated residuals. Where sufficiently thin and low-concentration residuals are present, short- and long-term mixing of the clean cover layer into underlying residuals will support attainment of the cleanup criteria. The placement of a clean cover layer accelerates the natural recovery process in the biologically active zone. Placing RMC has a similar purpose as placing an ENR layer to accelerate the natural recovery process.

For missed inventory residuals, a contingency re-dredging pass will be conducted over a portion of the RAA dredge footprint to remove material above the threshold concentration that will be developed as part of the CQAP post-dredge confirmation sampling plan.

The monitoring outcomes that will trigger RMC placement and/or contingency re-dredging will be developed in the CQAP. There may be some dredging areas that do not require RMC and/or contingency re-dredging, depending on the post-dredge monitoring results. However, for cost estimating purposes in this Preliminary (30%) RD, it is assumed that after required dredging is completed RMC will be placed in all dredge areas (plus an approximate 10-ft buffer surrounding the dredge area) that are not backfilled. The dredge residuals management approach (including sampling, reporting, decision logic, and communication) will be detailed in the CQAP in the Intermediate (60%) RD. The CQAP table developed for this Preliminary (30%) RD submittal is presented in Appendix F.

10.2.9 Post-Dredge Backfilling

Backfilling dredged areas with clean material will be required in some dredged areas to restore pre-construction elevations for habitat purposes. Backfill can also serve a residuals management function. This backfill layer is subject to erosive forces from localized propwash from vessels maneuvering within the project remediation area as well as river currents. The intent of the backfill is not to be resistant to every erosive force, but to generally remain stable to roughly the grades achieved after construction. Some movement of the material is anticipated. Post-dredge backfill is also appropriate where steeper (2H:1V) temporary dredge cuts need to be restored to a more stable (3H:1V) long-term slope, as discussed in Section 8.

For Preliminary (30%) RD, all dredge areas located outside of the FNC and above elevation -10 ft MLLW are assumed to be backfilled and integrated with habitat material placement in intertidal areas as appropriate. Additionally, some areas along EAAs will be backfilled where steeper temporary cuts are made within the EAA so that a more stable long-term backfill slope is created.

10.3 Engineered Cap Design

As discussed in Sections 5 and 6, engineered capping was selected as a component of the interim remedial action (partial dredge and cap) for the shoreline portion of Area 18 where contaminated sediments are not vertically bounded and cannot be removed within the dredging offset from the deteriorating bulkhead wall, and is therefore discussed in detail in this section. In addition to describing the general approach and components of an engineered cap, this section presents three design options for Area 18, including the preferred approach to integrate the adjacent upland cleanup with the in-water remedy.

Engineered capping may also be applied to similar areas that require dredging offsets from structures (depending upon limitations due to structure stability and impacts to raising grades in the dredging offset area) as the project is advanced to Intermediate (60%) and Pre-Final (90%) RD, or if deeper pockets (i.e., additional unbounded vertical extents) of contaminated sediments are encountered during Phase III PDI.

10.3.1 General Cap Design Approach

An engineered cap is designed in accordance with the guidance on cap design set forth by the EPA and USACE (Palermo et al. 1998) and the Interstate Technology and Regulatory Council (ITRC 2014). These guidance documents provide a generalized approach to designing an in situ cap, including considerations of the following specific design components detailed in Appendices G and H:

- **Chemical Isolation:** Designing cap chemical isolation layer that attenuates the transport of contaminants through processes such as advection, dispersion/diffusion, biodegradation/bioirrigation, and surface exchange. Contaminant fate and transport modeling is performed to evaluate and design the chemical isolation layer component of a cap.
- **Physical Isolation:** Designing cap layer thickness and/or material types to prevent direct contact of contaminants with biota and burrowing organisms (bioturbation). Physical isolation also includes developing design criteria to prevent erosion of the cap.
- **Geotechnical:** Confirming that the bearing capacity and shear strength of underlying sediments, and of the cap itself, are sufficient to prevent excessive mixing during construction

and slope failure. Geotechnical considerations for capping, including an evaluation of seismic risk, are discussed in Section 8.3.8.

An engineered cap typically consists of an erosion protection layer overlying a chemical isolation layer. However, cap design details will be developed during Intermediate (60%) RD, and the final cap design may combine the chemical isolation plus erosion protection layer as a single combined layer. For the upper reach, the ROD requires that the top of the cap has suitable habitat material in clamming areas. Details and results of the cap design evaluations and modeling are provided below and in Appendices G and H.

10.3.2 Area 18 Design Options

Area 18 includes contaminated sediments that are located within a dredging offset area (see Section 9.2) and where contaminated sediments are not vertically bounded. As discussed in Section 2.2, Area 18 is located generally between RM 3.7E and RM 3.8E and includes the Port of Seattle shoreline "sliver property" along a deteriorating bulkhead wall. Soils and groundwater with elevated concentrations of arsenic and other COCs are present within the "sliver property" and adjacent Boeing Isaacson Thompson upland cleanup area, which are under Ecology-led upland cleanup processes. This upland property adjacent to Area 18 is in the FS phase to evaluate remedial alternatives.

The following three options are available for management of the contaminated sediments that are present within the dredging offset and that are not vertically bounded:

1. **Option 1:** Defer in-water remedial work in Area 18 until an interim or final upland remedy is implemented and can integrate the in-water sediment remedy. This integrated approach is judged to be the most effective remedial option because all remedial construction work in this area could be completed in a coordinated, single effort. This option would reduce uncertainty in the effectiveness of the sediment remedy, avoid short-term impacts of a second construction event in this area, reduce recontamination risk associated with phasing remedial construction between in-water and upland activities, and potentially provide opportunity to enhance habitat.
2. **Option 2:** Design an interim in-water remedy that includes partial dredging and capping within a portion of Area 18 with the dredging offset and adjacent dredge slope. This approach may be able to temporarily address much of the contamination in Area 18. However, the interim remedy is susceptible to being recontaminated during upland cleanup actions. Additionally, clean material (e.g., backfill and cap materials) placed as part of the interim remedy would need to be removed and disposed of as contaminated material as part of the permanent cleanup.
3. **Option 3:** Install temporary shoring (e.g., steel sheetpiles) to buttress the deteriorating wooden bulkhead and allow for dredging up to the face of the temporary shoring. As noted above, portions of Area 18 are vertically unbounded. This management option was rejected because shoring cannot be installed immediately against the deteriorating bulkhead, and therefore some

remaining contamination would still be present between the shoring and the bulkhead. The necessary construction offset that allows for equipment to install the shoring, and the actual shoring dimensions, even if small, would result in this wedge of contaminated sediment that remains. The incremental environmental benefit provided by this approach compared to Option 2 does not justify the significant effort required to install the shoring because full mass removal would still not be possible.

Option 1 is the preferred option for the reasons noted above. Option 2 is presented in Preliminary (30%) RD since Option 1 design cannot be completed before the upland cleanup is designed, and the timeline may fall outside the current upper reach design schedule but within the overall timeline of the LDW cleanup. Option 2 is discussed in Section 10.3.3. The final design approach for Area 18 will be selected in coordination with EPA, Ecology, and upland property owners.

10.3.3 Area 18 Interim Cap Design Components

Engineered capping provides physical isolation and chemical attenuation of the contaminated sediments that remain and is currently limited to portions of the Area 18 shoreline. The cap in Area 18 is considered an "interim" cap that is proposed to be designed to be protective during a time period that exceeds the anticipated duration in which the adjacent upland MTCA remediation (outside of the LDW upper reach Superfund site) is performed. The cap duration for protection is assumed to be 10 years for purposes of the Preliminary (30%) RD. Future upland actions adjacent to Area 18 at the Boeing Isaacson-Thompson Site are anticipated to be integrated with the shoreline work, allowing the remaining material within the dredging offset area to be permanently addressed. Table 5-1 in Section 5 indicates partial dredging and capping technology is assigned to Area 18, consisting of a total area of approximately 0.3 acre.

10.3.3.1 Chemical Isolation Layer

Based on the ROD, LDW COCs include 4 chemicals based on risk to human health and 39 chemicals based on risk to benthic invertebrates. The chemical isolation functions of caps for specific locations are designed based on representative COCs at that location. In Area 18, PCBs and arsenic were evaluated.

Chemical Isolation Layer Design Criteria

The chemical isolation cap layer is designed to meet performance standards within the surface of the cap. Typically caps are designed to be effective at preventing contaminant mobility to exceed a compliance concentration at 100 years; for LDW, this would mean predicting cap performance to be below the surface (0-10 cm) RAL at 100 years. However, because the cap in Area 18 is "interim," the chemical isolation analysis was performed to identify the cap thickness and composition (i.e., amendment) needed to meet performance standards for PCBs and arsenic over a reasonable timeframe for the "interim" cap design. For the purposes of this evaluation, the timeframe deemed reasonable for an "interim" cap design is 10 years.

Chemical Isolation Layer Design Approach and Results

The one-dimensional model of chemical transport within sediment caps, Capsim (version 3.8; Reible 2017) was used for this evaluation. The model considers the transport of contaminants under the processes of groundwater advection, diffusion/dispersion, bioturbation/bioirrigation, and exchange with the overlying surface water within the sediment cap. As a conservative assumption, the ongoing sedimentation that will occur in most locations has not been considered in the cap design.

The cap model predicts the chemical concentrations that may occur in the surface of a cap over time. This analysis was performed to identify the cap thickness and composition (i.e., amendment) needed to meet performance standards for PCBs and arsenic. PCBs were simulated by homolog group to account for the differences in mobility among the homologs, and results were summed to calculate total PCBs in sediment for comparison with RALs.

Results of the cap model evaluation are described in Appendix G for the Area 18 cap area. That analysis demonstrated that a minimum chemical isolation layer thickness of 15 cm (6 inches) of sand would be sufficient to meet the PCB RALs for more than 100 years. Zero valent iron (ZVI) has been shown to be effective at attenuating arsenic in engineered caps (ITRC 2014) and was chosen as the assumed cap amendment for this evaluation. A preliminary analysis also showed that a minimum chemical isolation layer thickness of 15 cm (6 inches) of sand with 10% by weight ZVI may be able to meet the arsenic surface (0-10 cm [0-4 inch]) RAL for the interim 10-year period, with thicker chemical isolation layers needed if the 0-45 cm (0-1.5 ft) RAL also needs to be met. The evaluations assume that arsenic is present within upper reach sediments in the mobile phase.

10.3.3.2 Bioturbation

Another consideration in the design of engineered caps is to account for the potential for surficial and deeper-burrowing benthic organisms to burrow (i.e., bioturbation) into the cap and reach the subsurface contaminants. The biological active zone (BAZ) refers to the surface sediment layer where sediments are mixed by the feeding and burrowing behaviors of benthic invertebrates. A bioturbation thickness of 10 cm (4 inches) was used in the cap design where mixing by benthic activity was simulated. Section 2.8.2 of the RI (Windward 2010 concluded that 10 cm (4 inches) can be reasonably applied to the BAZ for the LDW based on several factors:

- **Representativeness of the benthic invertebrate community:** The benthic invertebrate community primarily utilizes shallower sediment based on the limited number of voids that have been observed below 10 cm (4 inches).
- **Relationship between voids and depth in sediment:** The number of voids decreases significantly with distance from the sediment surface.

- **Central tendency of void depth:** The mean of the maximum void depths observed in individual profile images was approximately 10 cm (4 inches) with a 95% upper confidence limit of 11 cm (4.5 inches).
- **Location:** Other than an association with fine-grained sediment, there were no apparent clusters of areas with deeper voids; voids seem to be distributed throughout the RI study area and not related to presence or absence of contamination.

The Area 18 cap will consist of an erosion protection layer that will limit the ability of organisms to reach the underlying chemical isolation layer component of the cap as discussed in Section 10.3.3.3 due to coarser grain size (more difficult burrowing) and thickness (greater than the 10-cm [4-inch] BAZ). Additionally, Area 18 is located within a potential clamming area per ROD Figure 6. The ROD requires placement of 45 cm (1.5 ft) thickness of habitat material at the top of the cap within intertidal clamming areas to provide sufficient thickness for clams to burrow such that the underlying erosion protection and chemical isolation layers are not disturbed by clam burrowing activity.

10.3.3.3 Erosion Protection

Caps are designed to be stable in perpetuity with regard to expected erosive forces. The design of the erosion protection layer includes determining the required cap erosion protection layer grain size and thickness to prevent cap damage from erosive forces, and potentially an underlying layer of material to prevent the migration (or “winnowing”) of the chemical isolation layer material (typically sand) through the interstices of the larger grain sized erosion protection layer. The top layer of the cap that acts as the erosion protection layer is typically referred to as an armor layer; the material under the armor layer that helps prevent winnowing is referred to as the filter layer. The cap erosion protection design may be able to avoid a discrete filter by integrating filter material both into the armor and chemical isolation layers, which is a common design approach. The detailed cap gradation design will be specified in Intermediate (60%) RD.

Per the RDWP, the cap has been designed to resist the following erosive forces: hydrodynamic flows, wind-generated waves, vessel propwash, and vessel wakes. The following sections summarize the erosion protection design presented in Appendix H. Climate change effects (e.g., sea level rise) on erosion protection design are discussed Section 11.4.

Hydrodynamic Flows

Hydrodynamic flows (i.e., LDW river flow velocities) are a natural cause of potential bed erosion. The FS prepared a hydrodynamic flow model for the LDW (QEA 2008) and predicted river velocities generated during a 100-year recurrence event. The 100-year flow recurrence is considered a standard design event for cap design, and the LDW sediment transport model predicted a maximum near-bed river flow velocity of 1.5 ft/s in Area 18. As discussed in Section 10.3.3.3 Vessel Propwash and Wakes, the design propwash velocity acting on Area 18 was estimated to be 0.5 ft/s due to the distance of Area 18 from the FNC. The hydrodynamic maximum river flow velocity in Area 18 is higher than the predicted design vessel propwash velocity at Area 18.

The stable particle sizes to resist the river flow velocities and propwash were evaluated using the methods in Appendix A (Armor Layer Design) of EPA's *Guidance for In-Situ Subaqueous Capping of Contaminated Sediment* (Palermo et al. 1998). The median stable particle size (D_{50}) at Area 18 to resist the 100-year hydrodynamic flows is 0.1 inch. As described below, the median stable particle size (D_{50}) at Area 18 to resist propwash forces is 0.25 inch. The reason that the median stable particle size for propwash is larger than for river flow, even though the velocity is lower, is that propwash is assumed to be a much more turbulent flow that results in higher bed shear stresses (see Appendix H).

Wind-Generated Waves

Wind-generated waves are formed by wind blowing over an unobstructed water surface. Wind-generated waves are formed due to continuous wind blowing in a single direction, over long distances (i.e., fetch). The LDW is narrow (between 250 and 450 ft wide); the water surface has obstructions that block the wind at various locations (e.g., South Park Bridge, bends in the waterway, high banks); and the LDW has restricted fetch[16] distances.

Seventy-nine years of wind data were collected from King County International Airport and an extreme analysis was conducted to find the 100-year wind speeds at various directions. Area 18 is near a bend in the LDW that has two fetches, one from the northwest and one from the south. The 100-year wind speeds are 43 mph from the northwest and 62 mph from the south. The fetch from the northwest is approximately 1.7 miles and the fetch from the south is approximately 0.9 mile. However, given the waterway is narrow, with a low width to length ratio, effective fetch factors were included to reduce the fetch lengths to 0.2 and 0.3 mile, respectively (Ippen 1966). Utilizing the FNC depth of 26.3 ft at MHHW, maximum wave heights for the 100-year wind speeds are 0.3 ft from the northwest and 0.6 ft from the south. Therefore, wind-generated waves will not grow to a height comparable to wakes caused by transiting vessels discussed in Section 10.3.3.3. Wind-generated waves are not a controlling design criterion for cap erosion protection design.

Vessel Propwash

In order to evaluate potential erosion forces from vessels transiting the upper reach, design vessels and assumed conservative operating conditions need to be identified. The design vessel selection and operating parameters are described in Appendix H.

[16] Fetch refers to the unobstructed overwater distance in the wind direction of interest. Fetch distance can be very long in large open water locations (e.g., oceans) and is very short where land masses and other wind obstructions (e.g., building, bridges) limit the ability of wind shear stress to act for sustained distance on the water surface.

Vessel-generated propeller-induced water velocity (i.e., propwash) was evaluated using the methods in Appendix A (Armor Layer Design) of EPA's *Guidance for In-Situ Subaqueous Capping of Contaminated Sediment* (Palermo et al. 1998). This model considers physical vessel characteristics (e.g., propeller diameter, depth of propeller shaft, and total engine horsepower) and operational and site conditions (e.g., applied horsepower and water depth) to estimate propeller-induced bottom velocities at various distances behind the propeller. This model was used to predict the particle size that will be stable when subjected to the steady-state propwash (i.e., the vessel is essentially stationary or maneuvering at a very low speed).

The FS evaluated a range of vessels operating in the LDW. Because the FS evaluations were conducted in 2009, recent vessel data were collected to determine whether different vessel characteristics (size, horsepower) should be considered. Vessel traffic data were obtained through the Automatic Identification System; vessel data are collected by the U.S. Coast Guard through onboard navigation safety devices that transmit and monitor vessel locations and characteristics of large vessels. These data were downloaded via MarineCadastre.gov (BOEM and NOAA 2021). Three representative vessels were analyzed; two tugs and one pleasure craft. The larger vessels are similar in size and horsepower to those considered in the FS. Design vessels are as follows:

1. Capt. Cae Tug
   a. The largest tug to transit the area in 2020 (92 ft long)
2. Westrac II Tug
   a. An average sized tug (74 ft long), selected to represent the more typical tugs that frequent the area; the average length for tugs that transited the area in 2020 was 72 ft
3. Arctic Pride Yacht
   a. One of the largest pleasure vessels to transit the area in 2020 at 126 ft long; there were three larger vessels (up to 150 ft long), but Arctic Pride transited more frequently

Appendix H provides further details of the propwash model design scenarios and inputs. The results of the propwash evaluation show that resulting bottom velocities and required median stable particle sizes are also fairly low (0.5 ft/s and 0.25 inches or smaller) for the design vessels and operating scenarios due to the distance of Area 18 from the FNC.

Vessel Wakes

Estimates of vessel-induced wave heights (i.e., wakes) were completed through an evaluation of ship traffic patterns within the navigation channel at Area 18 and calculations of vessel wakes based on type of vessel, operational speed, and water depths. The analysis used the Weggel and Sorensen (1986) methodology to predict vessel wakes. The calculated vessel wave heights were assessed for the Area 18 cap using the rubble-mound revetment module (USACE 2004) with Automated Coastal Engineering System developed by USACE (1992). This module was used to compute the median particle stone size (D_{50}) resistant to the predicted wake height based on the slope of the intertidal zone where caps would be placed. Based on this analysis, a stable median particle size diameter (D_{50}) of 3 inches would withstand vessel wakes within the breaking zone down to -6.7 ft MLLW.

Erosion Protection Summary

The armor layer material size is controlled by the largest particle size that is stable against a range of erosive forces in the upper reach, including hydrodynamic forces, wind-generated waves, and vessel-generated propwash and wakes. The stable particle sizes to resist the following forces are as follows:

- Hydrodynamic flows: 0.1 inch
- Wind-generated waves: Negligible
- Vessel propwash: 0.25 inch
- Vessel wakes: 3 inches

Therefore, the armor layer material size is controlled by the vessel wakes, which result in the largest sized material to provide erosion protection to the cap as compared to the other erosive forces.

10.3.3.4 Habitat Substrate Considerations for Caps

Habitat substrate is typically specified as a sand and gravel material with low fines content, and is coarser than naturally deposited sediments. Habitat substrate is intended to fill interstitial spaces of riprap (if needed for erosion protection) and to provide material over the riprap that can be used by benthos. Habitat substrate placed on riprap is not of appropriate size to resist the high-energy flows to which the riprap is typically subjected.

Habitat material is also used as backfill for areas with silts, sands, and/or gravels. The low fines content of sand and gravel habitat material reduces impacts associated with turbidity during habitat substrate placement. The placed habitat substrate will eventually be covered by naturally deposited sediment specific to each area placed, so in the long term the habitat surface will return to conditions reflecting what is naturally deposited from upstream.

The ROD requires placing 45 cm (1.5 ft) of habitat material as the top layer of a cap placed within intertidal clamming areas shown on ROD Figure 6. In flatter-slope areas where this is possible, cap areas within intertidal clamming areas will be designed to include 45 cm (1.5 ft) of habitat material overlying cap material while maintaining the approximate existing elevations. Where the intertidal clamming area includes steep or armored slopes, a 1.5-ft thick layer of this material will not be stable and will need to be reduced. Habitat substrate is also typically applied to improve the habitat value of riprap by applying an amount sufficient to fill the interstices of the riprap. Habitat substrate material type and material sources are discussed further in Section 10.5 and the material specification will be developed in Intermediate (60%) RD.

10.3.3.5 Area 18 Cap Design Summary

Based on the results of the cap design elements discussed in Sections 10.3.3.1 through 10.3.3.4, the interim cap design for Area 18 is summarized as follows, and a cross section is provided in Appendix D:

- Chemical isolation layer: Minimum of 15 cm (6 inches) of sand with 10% by weight ZVI with 15 cm (6 inches) of overplacement allowance
- Erosion protection layer: Minimum of 15 cm (6 inches) of gravel cobble (D_{50} of 3 inches) with 15 cm (6 inches) of overplacement allowance
- Habitat substrate for clams: Minimum of 45 cm (1.5 ft) with 15 cm (6 inches) of overplacement allowance

10.3.4 Other Potential Cap Areas in the Upper Reach

Cap modeling results in Appendix G indicate that sand caps without amendment are sufficient to meet the PCB RALs for areas where capping is identified as the selected technology (Section 5, Table 5-1). Additional cap areas in the upper reach may be identified during Intermediate (60%) RD, and the cap modeling presented in Appendix G will be updated accordingly.

10.4 Enhanced Natural Recovery Design

ENR includes the placement of a thin cover layer of clean sand to accelerate natural recovery processes. ENR immediately provides a new surface substrate of clean sediments. This cleaner surface material will generally mix with the underlying material, through mechanisms such as bioturbation. ENR reduces contaminant concentrations in surface sediments more quickly than would happen by natural sedimentation processes alone. Findings from the ENR/AC Pilot Study Year 3 Monitoring Report (Wood et al. 2021) indicate that ENR alone (without AC) is effective at reducing bioavailability of PCBs (90% reduction). The ENR/AC Pilot Study also demonstrated that the ENR remained in place and performed as intended under various physical conditions (e.g., wakes/waves, propwash, bridle chain dragging) over the 3-year study.

ENR may be combined with in situ treatment (i.e., the sand layer may be amended with AC or other sequestering agents to reduce the bioavailability of organic contaminants such as PCBs). The effectiveness and potential impacts of using in situ treatment or amendment technologies, as well as the areas best suited for these technologies, were evaluated in the ENR/AC Pilot Study. The ENR/AC Pilot Study concluded adding AC to the ENR layer provided no substantial improvement in PCB bioavailability reduction when compared to ENR alone (Wood et al. 2021). The study also showed that the amount of AC used (2.7% to 4% by weight AC) did not adversely impact benthic communities.

AC amendment is not included in ENR as part of the Preliminary (30%) RD. If AC amendment is selected as a component during a subsequent phase of the RD, AC vendors that can meet the design quantities and other prescriptive criteria established for AC will also be identified as part of the Intermediate (60%) RD. In addition, amendments for other contaminants such as metals are not included as a design component of ENR as part of the Preliminary (30%) RD.

Consistent with the ROD and recent Puget Sound projects, ENR will include placement of a minimum 6-inch-thick layer of clean sand (or other suitable habitat materials) on in situ sediments. Per the ROD, ENR can be used in Recovery Category 2 and 3 areas only where concentrations are less than 3 times the RALs in surface (0-10cm) sediments and are less than 1.5 times the RALs in intertidal subsurface (0-45 cm) sediments. Table 5-1 in Section 5 indicates ENR technology is assigned to Areas 7, 10, 23, 25, and 33, consisting of a total area of approximately 4,000 sq ft.

10.5 Material Types and Placement Methods

Material placement types included in this Preliminary (30%) RD include backfill, engineered cap chemical isolation layer material and associated amendments, engineered cap erosion protection armor, ENR, RMC, and habitat substrate. The anticipated types of material, sources, placement methods, and production rates are discussed in this section.

10.5.1 Material Types

Table 10-2 summarizes each of the material types needed for the project. During Intermediate (60%) RD, detailed gradations will be developed in the specifications. Once cap material specifications and volumes have been developed, specifications will be developed to specify means and methods for cap material transport, handling, and placement.

Table 10-2
Summary of Material Types

Material Type	Material Description
Cap Chemical Isolation Layer	Medium to coarse gain sand. ZVI amendment added in areas with As exceedances
Cap Erosion Protection Layer	Gravel cobble with a D_{50} of 3 inches
Habitat Substrate	Suitable fine to medium sand for clam habitat areas; fish mix may be used in other habitat areas outside of clamming areas and will be determined in coordination with EPA
ENR	Coarse sand or gravelly sand depending on location and depth of ENR. No amendment is anticipated, and total organic carbon is expected to recover within 1 to 3 years
Residuals Management Cover Material	Medium to coarse grain sand
Backfill Material	Gravelly sand or coarse sand material

Notes:
ENR: enhanced natural recovery
EPA: U.S. Environmental Protection Agency
TOC: total organic carbon
ZVI: zero valent iron

10.5.2 Candidate Source Material Suppliers

Materials will be obtained from established upland borrow sources. There are several regionally available commercial sources of aggregate material (i.e., sand and gravel quarries) that can supply materials for backfill, capping (e.g., sand, gravel, armor) and RMC and ENR (e.g., sand and gravel). Locally available sources of aggregate material include the following:

- Glacier Northwest commercial sources (e.g., Dupont Pioneer Aggregates, White River, Snoqualmie locations in Washington)
- Main Plant, a sand and gravel facility in Sumner, Washington
- Valley View/Dieringer Pit, a sand and gravel pit in Shelton, Washington
- Baydo, a gravel facility in Auburn, Washington
- Johns Prairie Mine, a sand and gravel pit in Shelton, Washington
- Kent-Kangley Pit, a sand and gravel pit in Ravensdale, Washington
- Miles Sand and Gravel, multiple aggregate pit locations in Puget Sound region, Washington

The contractor will ultimately select appropriate material suppliers that can meet the design quantities, delivery schedules, gradations, and chemical quality criteria established for each material type. The specific supplier(s) will be identified as part of construction submittals.

Beneficial use of clean dredged material from off-site non-remediation projects was evaluated as a potential source of backfill, ENR, RMC, and cap attenuation layer materials. Beneficial use of clean dredged material entails significant legal, contracting, logistic, coordination, and timing complications, among other issues, and for recent cleanup projects has been difficult to accomplish. Given the anticipated schedule for cleanup in the upper reach, and the uncertainty of the timing, quantity, and quality of future dredging project volumes, beneficial use of clean dredged material is not included as part of the Preliminary (30%) RD assumptions and will be further evaluated in Intermediate (60%) RD.

10.5.3 Source Material Acceptance Criteria

Cap, backfill, ENR, RMC, and habitat materials must be approved for use by the Implementing Entity and by EPA; therefore, testing of the borrow source material will be required of the contractor to demonstrate that the source material meets EPA-approved chemistry criteria. Chemical criteria, gradation, material properties, and testing requirements will be identified in the specifications, and summarized in the CQAP, both to be developed in Intermediate (60%) RD.

10.5.4 Material Placement Methods

Project specifications to be developed in Intermediate (60%) RD will identify performance criteria that the contractor must meet and provide flexibility for the contractor to choose the optimal means and methods that take advantage of their experience and equipment. The contractor will be required to place all materials in a manner that reduces resuspending potentially contaminated bed sediment. Additionally, material will be placed using methods that limit mixing of the placed materials with the sediment. Exhibit 10-2 depicts in-water placement of clean material using typical marine equipment.

The following methods are considered acceptable placement methods, or combination of methods, that the contractor may use to limit disturbance of the bottom sediments during material placement operations. The contractor will be allowed to propose alternate placement methods in their RAWP for review and approval by the Implementing Entity and EPA:

- Placing cap, backfill, ENR, habitat, and RMC materials with a barge-mounted, crane-operated clamshell or a spreader box ('skip box'). The clamshell placement method involves slightly opening the bucket and slowly releasing the sand from the bucket near or slightly below the water surface as the operator moves the bucket in a sweeping motion from side to side. Allowing sands to fall through the water column helps spread out the placed materials that may help reduce the energy of the placed material hitting the bed.
- Placing cap, backfill, ENR, habitat, and RMC materials from a barge with a variable-speed telebelt, which would project material over the placement area. This placement method has been demonstrated locally (e.g., at the Todd Shipyard remediation project on Harbor Island, completed in 2006 in underpier areas with limited access for standard marine equipment.)
- Placing individual engineered cap layers by lowering the cap material close to the sediment bed surface and slowly opening the bucket to provide more accurate placement of each discrete cap layer.
- Placing larger armoring layer material from near the sediment bed instead of from the surface of the water column.
- On slopes, placing materials from the bottom of the slope and working up the slope to reduce the potential for slope sloughing.
- Placing materials using upland earthwork equipment from the shoreline and in intertidal areas working at low tides "in the dry."

10.5.5 Placement Tolerances and Verification

In Intermediate (60%) RD, the drawings and specifications will specify the required thicknesses of cap, backfill, ENR, RMC, and habitat material layers and overplacement allowances for material placement. Materials may be placed in single lifts for ENR and RMC, and multiple lifts may be needed in backfill and capping areas.

The specifications will require the contractor to perform QC during material placement activities in accordance with the specifications and the contractor's RAWP (e.g., frequent progress surveys, pre- and post-placement acceptance surveys, bucket maps, quantity documentation, equipment inspection, sampling and analysis to verify imported materials quality). Construction QA will be performed by the Implementing Entity to review and accept specified material layer thicknesses before overlying layers of material are placed. The CQAP that will be developed during Intermediate (60%) and Pre-Final (90%) RD will describe QA roles and responsibilities, QA activities, and the means and methods that the Implementing Entity and its consultant will use to provide QA during construction to assess compliance with specifications. Contractor QA/QC is discussed further in Section 16.

Exhibit 10-2
In-Water Placement of Clean Material Using Typical Marine Equipment

Controlled bucket placement

Variable speed telebelt placement

10.5.6 Material Placement Production Rates

Similar to dredge production rates presented in Section 10.2.4, material placement production rates (i.e., the volume of material placed on an hourly or daily basis) will vary based on the contractor's selection of equipment, water depth, material types and physical characteristics (e.g., sand, gravel, armor), and site constraints such as nearby vessel traffic and weather conditions. It is estimated that a reasonable mechanical material placement production rate in the upper reach will be approximately 1,200 cy per day in open-water areas, such as the FNC. Material production rates are anticipated to be lower for nearshore and restricted access placement, as well as capping placement, which are estimated to range from approximately 700 cy to 1,000 cy per day. The overall site-wide weighted average placement production rate is estimated to be 1,100 cy per day.

Similar to estimating dredging production rates, other factors will affect production rates, may increase overall duration, and must be accounted for in the contractor’s schedule. These include, for example, QA/QC and Implementing Entity acceptance of each layer, water quality protection, scheduled downtime, directed moves to allow safe passage of commercial vessels, inherent delays, maintenance, inclement weather, holidays, or slowdowns due to bottlenecks at other portions of the operation (i.e., material procurement and delivery).

10.6 Monitored Natural Recovery

MNR is applied to sediment areas outside of the RAA and EAA boundaries that are not remediated through dredging, capping, or ENR. The compliance monitoring and decision framework regarding MNR will be developed in the Long-Term Maintenance and Monitoring Plan (LTMMP; Appendix I). As stated in the ROD, MNR is split into two categories that will be further described in this section: MNR to benthic SCO and MNR below benthic SCO (EPA 2014).

10.6.1 MNR to Benthic SCO

In MNR areas that exceed the benthic SCO, compliance monitoring of surface sediments (top 10 cm [4 inches]) will be implemented to evaluate whether the Remedial Action Objective 3 cleanup levels (benthic SCO criteria) are projected to be achieved.

Sample locations where MNR to benthic SCO may apply were originally presented in the DER (Anchor QEA and Windward 2022a). Table 10-3 and Figure 10-1 provide an updated summary. Additional samples will be proposed at some of these locations in the Phase III QAPP Addendum to evaluate how surface sediment COC concentrations are changing over time as projected by natural recovery models. MNR to benthic SCO areas will be defined during the Pre-Final (90%) RD. Additionally, modeling will be completed during Pre-Final (90%) RD to confirm that the MNR to benthic SCO approach is appropriate for each of the areas.

Table 10-3
Locations with Surface Sediment COC Concentrations > Benthic SCO and < RAL that Are Not Within an RAA

Sample (Year Sampled)	Location	COC	EF Relative to Benthic SCO	EF Relative to RAL[1]
DR203 (1998)	RM 3.28 W	Phenol	1.7	0.85
LDW20-SS156 (2020)	RM 3.4 in FNC	Mercury	1.1	0.56
DR209 (1998)	RM 3.71 W	Phenol	1.0	0.51
04-intsed-3 (1996)	Slip 6 N	Mercury	1.6	0.8
LDWSS383 (2020)	West side of Turning Basin	Dibenzofuran	1.3	0.67
LDWSS384 (2020)	West side of Turning Basin	Individual PAHs	1.2–1.3	0.58–0.63
R79 (1997)	East side of Turning Basin	Individual PAH	1.3	0.63
DR254 (1998)	East side of Turning Basin	Lead	1.4	0.69
NFK005 (1994)	RM 4.94 E	BEHP	1.4	0.71
LDW21-SS599 (2021)	RM 3.82E	BEHP	1.6	0.79
LDW21-SS625 (2021)	RM 3.92E	BBP	1.4	0.72
AN-014 (2006)	RM 4.0 E	Fluoranthene Phenanthrene	1.3 1.7	0.63 0.85
AN-040 (2006)	RM 4.0 E	BBP	1.3	0.65

Notes:
1. The RAL is twice the benthic SCO in Recovery Category 2/3 areas, so the exceedance factor relative to the RAL is one-half that relative to the benthic SCO.

BBP: benzyl butyl phthalate
BEHP: bis(2-ethylhexyl) phthalate
COC: contaminant of concern
EF: exceedance factor
FNC: federal navigation channel
PAH: polycyclic aromatic hydrocarbon
RAA: remedial action area
RAL: remedial action level
RM: river mile
SCO: sediment cleanup objective

10.6.2 MNR Below Benthic SCO

MNR below benthic SCO areas will be monitored as part of the site-wide monitoring program to track progress toward achieving Remedial Action Objectives 1 and 2. MNR below benthic SCO generally encompasses most areas of the LDW outside the RAAs, and the associated MNR regime will be presented in the LTMMP.

10.7 Flood Rise Analysis

Based on the remedial approach presented in this Preliminary (30%) BODR, it is expected that the total quantity of material dredged will be greater than the total fill quantity placed for backfill, capping, ENR, and RMC and thus will result in a net increase in flood flow capacity within the upper reach, which will act to lower the overall flood level in the reach. Therefore, it is expected that the RD will not result in a predicted increase to the flood levels of the 100-year flood discharge. At Preliminary (30%) RD, the estimated total dredging volume (including assumed contingency re-dredging volume) is 117,700 cy; the estimated total placement volume for backfill, capping, ENR, and RMC is 67,800 cy.

Per the Federal Emergency Management Agency (FEMA) Region 10 guidance document, *Procedures for "No-Rise" Certification for Proposed Developments in the Regulatory Floodway* (FEMA 2013), the equivalent to a "no-rise" certification may need to be demonstrated for the upper reach remedial action based on hydraulic analyses to demonstrate substantive compliance with Section 60.3(d)(3) of the National Flood Insurance Program and implementing regulation King County Code Section 21A.24.240 (zero-rise flood fringe). These codes stipulate that any development or alterations to the floodplain shall not increase the base flood elevation or energy grade line elevation during the occurrence of the 100-year flood discharge.

If a zero-rise evaluation is determined to be required by EPA during ARAR substantive compliance concurrence, the USACE's Hydrologic Engineering Center – River Analysis System (HEC-RAS) hydraulic model will be used to evaluate the effect of the remedial action on the 100-year flood elevation during Intermediate (60%) RD. This model would be used to estimate the pre-construction and post-construction flood stage elevations in the upper reach. HEC-RAS is the FEMA-accepted modeling tool used for determining the base flood elevations reported in FEMA Flood Insurance Studies. The existing HEC-RAS floodplain model developed by FEMA for the Duwamish River would be evaluated to consider how well it represents pre-construction conditions and would be modified to reflect proposed work in the upper reach to represent post-construction conditions. Modeling work, if needed, would be conducted recognizing that other significant factors, such as ongoing sediment deposition within the FNC and regular maintenance dredging performed by USACE in the FNC and Turning Basin[17], may outweigh the potential effects of remedy construction with respect to the results of the flood rise analysis.

10.8 Maintenance, Monitoring, and Institutional Controls

Maintenance, monitoring, and institutional controls will be implemented in accordance with the LTMMP (Appendix I), and the Sediment Remedy Institutional Controls Implementation and Assurance Plan (Sediment Remedy ICIAP; Appendix J). Per AOC4, the Preliminary (30%) RD includes outlines of the LTMMP and Sediment Remedy ICIAP. Comments on these outlines will be addressed during Intermediate (60%) and Pre-Final (90%) RD. Final (100%) RD will include annotated outlines of the documents.

[17]The FNC is typically dredged by USACE every 2 to 3 years from the turning basin to approximately RM 4.0.

The Implementing Entity, working under a forthcoming Consent Decree or other enforcement mechanism, will finalize and implement the LTMMP and Sediment Remedy ICIAP after construction is completed. It is expected that the LTMMP and Sediment Remedy ICIAP will be subsequently amended to include site-specific requirements for each reach following construction.

The purpose of the LTMMP is to assess the following:

- Remedy performance compared to the ROD criteria
- Compliance with ARARs
- Integrity of the remedial actions
- Develop information for EPA's periodic reviews of the remedy

The LTMMP will describe performance standards; sampling (type, density, and frequency); interim benchmarks (if applicable); and associated follow-up or response actions. The LTMMP will be developed in accordance with *Guidance for Management of Superfund Remedies in Post Construction* (EPA 2017). The LTMMP will include both LDW-wide monitoring elements as well as elements specific to the remedy in the upper reach, such as specific monitoring requirements for caps, ENR, and MNR to benthic SCO.

The purpose of the Sediment Remedy ICIAP is to identify the institutional controls necessary to protect the physical integrity of remedial actions. The Sediment Remedy ICIAP will include an evaluation of the most appropriate institutional, proprietary controls and location-specific use restrictions needed to support long-term effectiveness of the remedial action, consistent with Section 13.2.4 of the ROD (EPA 2014). The Sediment Remedy ICIAP will be developed in accordance with *Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites* (EPA 2012a) and *Institutional Controls: A Guide to Preparing Institutional Controls Implementation and Assurance Plans at Contaminated Sites* (EPA 2012b). Because much of the upper reach entails dredging to a surface that is below RALs, the need for protective institutional controls is expected to be limited.

For the protection of risks to human health from resident seafood consumption, EPA and Public Health Seattle-King County established a community-based Duwamish Healthy Seafood Consumption Institutional Control Program for the LDW Superfund Site (Public Health Seattle and King County 2019). To avoid redundancy, the Sediment Remedy ICIAP will refer to the Duwamish Seafood Consumption ICIAP for institutional controls related to reducing risk from consuming contaminated resident seafood from the LDW, and thus, will not be repeated in the Sediment Remedy ICIAP. Per AOC4 requirements, the Preliminary (30%) RD includes an outline approach of the Sediment Remedy ICIAP (see Appendix J). Final (100%) RD will prepare an annotated outline of the Sediment Remedy ICIAP. The Implementing Entity will complete and implement the Sediment Remedy ICIAP after construction is completed, such that the ICIAP accurately reflects the details of the constructed remedy.

11 Environmental Protection During Construction

This section describes environmental protection considerations and requirements during construction, such as any controls that will be employed to comply with ARARs and reduce environmental impacts (in accordance with Section 13.2.5 and Section 13.2.8 of the ROD).

11.1 Water Quality Impacts During Construction

Dredging and material placement will generate short-term turbidity caused by resuspended sediments in the water column as well as some release of COCs associated with the sediment and porewater; causes of sediment resuspension are described in this section. Compliance with water quality criteria and anticipated monitoring are also discussed.

11.1.1 Water Quality Criteria

The contractor is responsible for providing quality control of its work to meet applicable and relevant state water quality criteria (WAC 173-201A-210; see Section 3.2.5), including turbidity, dissolved oxygen, pH, and temperature. Dredging impacts on water quality are typically assessed by complying with the provisions of EPA's Clean Water Act Section 401 Water Quality Certification. The Section 401 certification provisions will be based on state turbidity water quality standards, which are at WAC 173-201A-210(1)(e) for waters designated as "excellent" marine quality. Expected provisions of the 401 certification are that in-water construction activities do not increase the in-water turbidity, measured as Nephelometric Turbidity Units (NTU), more than 5 NTU above background (or 10% above background if background is 50 NTU or higher). Compliance is typically measured at the edge of the designated mixing zone (e.g., 150 ft to 300 ft away from the work activity at the compliance point). The Section 401 certification will specify the detail of any chemical monitoring required during the remedial action.

For contaminants in sediment targeted for dredging that could enter the water column due to resuspension, the acute and chronic criteria for protection of aquatic life in marine water are the applicable water quality criteria. Applicable water quality criteria are the minimum federal standards (40 CFR 131.45) and Washington State standards (173-201A WAC) for protection of aquatic life, and are listed in Appendix K.

The Section 401 certification is typically finalized following approval of the 100% design and will specify details of any chemical monitoring required during the remedial action. A Water Quality Monitoring Plan (WQMP) will be developed in consultation with EPA at Pre-Final (90%) RD and will reflect the likely requirements of the Section 401 certification. The WQMP will be updated by the Implementing Entity, in coordination with EPA, as required prior to the start of construction to reflect the final Section 401 certification requirements.

11.1.2 Sediment Resuspension During Dredging

Dredging of contaminated sediments results in temporary water quality impacts during construction. Therefore, significant effort has been made to understand and limit water quality impacts during remediation (e.g., *The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk;* USACE 2008b). As a result, there is an established set of tools commonly used for analyzing water quality impacts during sediment remediation and typical approaches employed for managing those impacts.

The USACE developed the DREDGE Model (Hayes and Je 2000) to help predict the impacts of dredging on contaminant concentrations within the water column. The details of this analysis are provided in Appendix K and summarized here.

Two sets of input parameters were developed. Acute water quality criteria were compared to potential short term (i.e., 1-hour; 24-hour for PCBs) impacts based on an assumed maximum hourly dredging production rate of 180 cy/hour and maximum sediment concentrations in core data. Chronic water quality criteria were compared to potential longer term (i.e., 4-day; 24-hour for PCBs) impacts based on an average dredging production rate of 1,000 cy/day and mean sediment concentrations in core data. During dredging for both scenarios, 3% of the dredged material volume was assumed to be resuspended into the water column. The ambient river flow and tidal velocities within LDW vary; however, a range of potential river flow velocities was evaluated to represent average flow conditions in the river.

In summary, based on site-specific model inputs to the DREDGE Model, no acute or chronic water quality exceedances are predicted for COCs at the compliance point of 150 ft or greater from the work zone during dredging activities.

11.1.3 Dredge Return Water

Remedial activities will consist of mechanically dredging contaminated sediment and placing the dredged materials onto a haul barge. Dredging results in capturing both sediment and added site water, especially if environmental buckets are used. For Preliminary (30%) RD, a bucket fill factor was assumed to be 70%, which conservatively assumes that the dredging results in capturing 3 parts water for every 7 parts of sediment.

Excess water from the haul barge, which is generated from the captured water and porewater from sediment as the sediments dewater on the barge, is typically collected on the barge, filtered to remove suspended solids (e.g., by passing through geotextile filter fabric), and then released back to the receiving water within the dredging work zone. This is referred to as dredge return water. Water quality from the entire dredging operation (including both the direct effects of the dredging and the release of the dredge return water) will need to comply with appropriate quality standards at the approved points of compliance (Section 11.1.1). Potential water quality impacts during barge dewatering were estimated by calculating the dissolved contaminant concentrations in the dredge return water based on sediment bulk chemistry and equilibrium partitioning theory, and assuming that porewater in the sediment fully mixes with the captured water. This is a very conservative assumption because sediment porewater is mostly retained within the sediment matrix and will not fully mix with the added captured water. This assumed "fully mixed" water concentration is then used as the dredge return water concentration, and the dredge return water load is assumed to be based on the volume of the captured water. The impacts within the area of mixing were calculated based on the procedures in *Evaluation of Dredged Material Proposed for Discharge in Water of the U.S. – Testing Manual,* Appendix C (USACE 1998) and are presented in Appendix K.

In summary, no acute or chronic water quality exceedances are predicted for COCs at the edge of the designated mixing zone (assumed to be150 ft or greater) from the dredging and barge discharge activities.

11.1.4 Sediment Resuspension During Material Placement

Material placement activities will result in short-term, localized sediment resuspension, and therefore, turbidity. Turbidity has been observed during clean material placement even when materials with very low fines content have been used. This turbidity will be transient and generated by clean aggregate material, mostly from the finer fractions of the clean aggregate material as it descends through the water. However, some resuspension of the bed sediment could occur depending upon the contractor's placement method. Sediment resuspension during material placement may also result from propwash disturbance from marine equipment and attendant vessels (e.g., tugboats).

Disturbance of the existing bed sediments during material placement is commonly managed by specifying limits on the initial lift thickness of placed materials (if needed), to avoid bearing capacity failure of the sediments (see Section 8), as well as requiring placement techniques that spread the placed material.

Experience in Puget Sound has shown that a common cause of turbidity exceedances is suspension of fines in clean materials being placed (for cap, ENR, etc.) even after BMPs are employed. Turbidity from clean fines in the placement materials can be reduced to an extent by limiting the fines content in the materials specification. However, some fines are always present and the need to evenly spread the placement material will result in the resuspension of the clean fines. Because these types of turbidity exceedances are localized and short term, it is generally considered that the net benefit provided by placing clean material as backfill, ENR, cap, or habitat substrate outweighs the short-term effects of localized turbidity exceedances.

Many of the other resuspension mechanisms mentioned above will be limited through BMPs (see Section 11.2).

11.1.5 Water Quality Monitoring During Construction

As part of the CQAP, a WQMP will be developed at the Pre-Final (90%) RD phase. The WQMP will describe the monitoring program intended to provide QA that the contractor's operations are in compliance with water quality criteria and potential corrective measures in response to water quality observations. The WQMP will describe the monitoring methodology and equipment, monitoring locations (e.g., early warning, compliance, and background stations), water quality criteria (listed in Section 11.1.1), monitoring frequency and schedule, and potential response/corrective actions in the event of a water quality exceedance. In addition, the WQMP will also identify communication and response protocols with EPA.

11.2 Construction Best Management Practices

BMPs are management practices that are determined to be effective, practical, and sustainable means of achieving an environmental performance objective. The specifications developed during Intermediate (60%) RD will identify specific performance criteria for environmental protection (e.g., water quality criteria). BMPs will be used to meet those performance criteria during construction and to limit, to the extent practical, potential adverse construction impacts and the magnitude of residual contamination. This section describes BMPs that may be implemented by the contractor during the dredging, offloading/transloading, upland transportation, disposal, and material placement (e.g., backfilling, capping, ENR, RMC) operations. The contractor may propose additional BMPs in their RAWP, subject to review and approval by EPA and the Implementing Entity.

11.2.1 Operational Controls to Reduce Sediment Resuspension

Operational controls are the procedures that a contractor implements to prevent or reduce potential sediment resuspension. Potential water quality impacts from sediment resuspension associated with in-water work are expected to be temporary and located at or close to the point of disturbance. Water quality monitoring has been conducted during the construction of the EAAs and many similar regional sediment remediation projects. The most common water quality issue observed has been occasional exceedances of turbidity criteria, either during dredging or placement of clean materials (e.g., capping, ENR, backfill, RMC).

Operational controls are one approach to reduce potential sediment resuspension and include actions or modifications that can be applied by the dredging/placement operator to their standard operational practices, to help reduce the potential environmental impacts of the dredging/placement operations (USACE 2008a). Operational controls to reduce sediment resuspension can include a broad array of methods; however, prescriptive requirements may not prove effective since equipment types and dredging methods will vary. Establishing performance criteria for water quality and allowing some degree of flexibility to the contractor in using operational controls allows them to customize their operations to effectively meet the performance standards.

Standard operational controls to reduce sediment resuspension that will be evaluated for inclusion as requirements in the specifications are listed below; actual selected operational control requirements will be incorporated into the specifications developed during Intermediate (60%) RD:

- Removal of large to medium-sized debris, if practicable, will be required prior to dredging in known debris areas (Exhibit 11-1 depicts typical debris encountered prior to dredging). Debris caught in dredging equipment can cause additional resuspension and release of contaminated sediments. Note this operational control is not appropriate for buried debris below the mudline.

Exhibit 11-1
Debris encountered for removal prior to dredging

- Multiple bites by the dredge bucket on the sediment bed before ascending to the surface will be prohibited, so that bed disturbance by the bucket is reduced.
- “Sweeping” (i.e., dragging a bucket or beam) or leveling of the sediment bed by pushing bottom sediments around with the dredge bucket to knock down high spots to achieve required dredge elevations will be prohibited. Instead of leveling to remove high spots, the contractor may be required to make an additional dredging pass to remove any high spots that are identified during post-construction surveys. Note that leveling may be an appropriate step for fill placement to create habitat surfaces that are relatively leveled and within the appropriate elevation range. Leveling clean fill materials to reduce low spots can improve the performance of specific habitat types.

- Interim underwater stockpiling of dredge material will be prohibited (i.e., taking small dredge cuts and temporarily stockpiling material at the mudline in a mound to allow the dredge operator to grab a fuller bucket). Such action could create a pile of loose sediment that can easily be resuspended.
- Overfilling of conventional clamshell and environmental buckets will be prohibited. When the dredge bucket penetrates into soft sediment, there is the potential for the bucket to penetrate beyond the designed digging depth of the bucket. If the bucket is overfilled, a portion of the dredged material cannot be contained within the bucket and may be lost and resuspended in the water column as the bucket is raised. If bucket overloading is observed, measures will be taken to reduce this potential (e.g., decrease the maximum cut depth).
- Selection of the appropriate dredge bucket for site-specific conditions will be required (i.e., soft sediment versus debris or hard digging)—using an environmental (closed) bucket where unconsolidated sediments exist, and using a different (e.g., digging) bucket in areas where an environmental bucket cannot fully close or cannot penetrate the sediment.
- Maintaining stable side slopes during dredging (e.g., shallow top-to-bottom cuts) will be required to prevent the potential for slope failures and slope movement that would cause sediment resuspension.
- All barges transporting dredged materials will be required to be certified as watertight by a marine inspector prior to barge use.
- Uneven filling and over-filling of barges beyond the top of the side rails will be prohibited, to prevent spillage from barges.

Additional BMPs to reduce sediment resuspension that may be additionally evaluated for inclusion as requirements in the specifications to manage water quality and meet turbidity criteria include the following:

- Slowing down the rate of dredge bucket descent and ascent; however, this BMP needs to be carefully implemented based on the physical characteristics of the sediments being removed (e.g., soft sediments versus hard digging, presence of debris, water depths) because limiting the velocity of the descending bucket in dredge operations may reduce the volume of sediment that is picked up by the bucket, thus requiring multiple bites to remove the project sediment and increasing the overall project duration and associated duration of short-term water quality impacts.
- After placing dredged sediment into the haul barge, holding the opened bucket for a short period of time above the barge to allow residual materials from the bucket to fall into the barge.
- After placing dredged sediment into the haul barge, washing the bucket to remove loose residual materials from the bucket before lowering into the water.

- Use of the lowest feasible power for tug operations will be recommended during barge relocation, movement for maritime traffic, and dredge/material barge replacements to reduce sediment resuspension.

Operational controls that are overly restrictive will reduce production rates and may increase the overall project duration, which would increase the duration for potential short-term environmental impacts. Thus, the advantages of applying operational controls needs to be considered in light of this reduction in efficiency and appropriately balanced to support environmental protectiveness (USACE 2008a).

11.2.2 Specialized Equipment

11.2.2.1 Environmental (Closed) Buckets

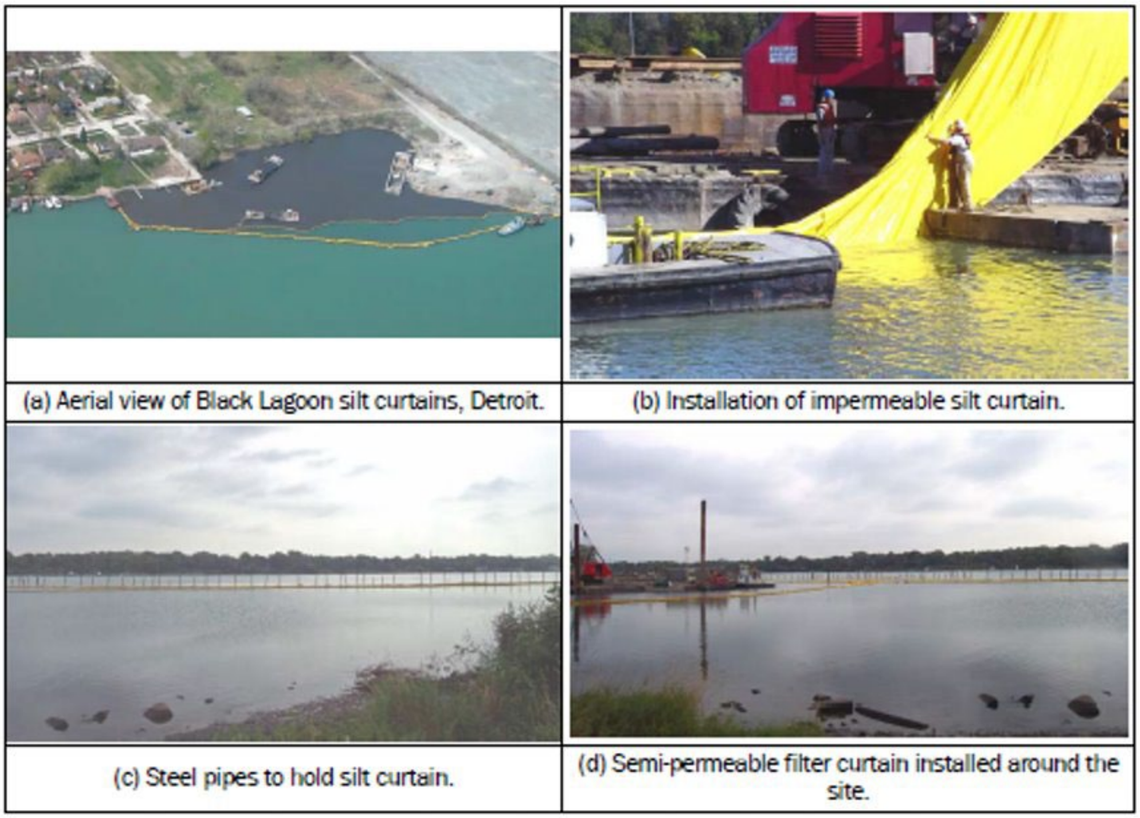
For mechanical dredging, this technology consists of specially constructed dredging buckets designed to reduce the loss of dredged materials from the bucket during dredging, when used properly and in the appropriate site conditions. Environmental buckets are discussed in Section 10.2.1.

Environmental buckets will be specified to be available as a required BMP for dredging to reduce sediment resuspension, but the specifications will allow the contractor to use other buckets (e.g., digging buckets, rehandling buckets) as site conditions warrant to achieve both the required dredging elevations and thicknesses, and to meet environmental protection criteria (e.g., water quality criteria).

11.2.2.2 Silt Curtains

A silt curtain is a constructed floating physical barrier that is positioned around the marine equipment (or the immediate area of dredging/placement) to reduce suspended sediment transport that is generated during dredging or placement operations. Silt curtains do not treat sediment resuspension or turbidity; rather, they direct and restrict the movement of the resuspended sediment and associated contamination to a smaller area (USACE 2008a). Exhibit 11-2 depicts a typical silt curtain installation. Silt curtains are typically constructed of flexible, reinforced, geotextile material with flotation elements in the upper hem and ballast material in the lower hem.

Exhibit 11-2
Examples of silt curtain installation (Black Lagoon, Detroit River, Michigan)



(a) Aerial view of Black Lagoon silt curtains, Detroit.

(b) Installation of impermeable silt curtain.

(c) Steel pipes to hold silt curtain.

(d) Semi-permeable filter curtain installed around the site.

Source: USACE (2008a)

Because they are mostly impermeable, silt curtains are easily affected by tides and currents and their effectiveness can be adversely impacted by high current velocities, moderate to large wave conditions, or large tidal variation. Silt curtains are more effective on projects where they are not opened and closed to allow equipment access to work areas. For more complex site configurations, larger sized dredge areas, and active vessel traffic, silt curtains need to be frequently moved, repositioned, and re-anchored, thereby reducing effectiveness and overall dredging production rates and increasing the duration of construction and overall short-term impacts from the dredging operations (EPA 2005). Typical silt curtain systems interfere with vessel navigation so they are usually not utilized in active navigation channels.

Traditional silt curtain barrier controls are designed to provide either containment of the full depth or partial depth of the water column. Partial-depth curtains are more typically applied when there is a tidal range to prevent the curtain from sitting on the bottom where the curtain could cause resuspension and/or be buried under sediment requiring constant maintenance. Full-depth curtains are either anchored directly into the mudline along a fixed alignment or affixed to installed vertical pilings or other existing in-water infrastructure. Similarly, partial-depth curtains can also be anchored or affixed to pilings or in-water infrastructure and extended from the mudline upwards into the water column, or they can be deployed from the surface of the water with a series of floats and bottom weights to extend the curtain to the target depth. Partial-depth curtains can be less effective than full-length curtains because the curtain does not extend the full depth of the water column, allowing passage of water and suspended solids below the curtain extent, in effect redirecting suspended sediments near the bottom.

Use of a silt curtain was evaluated for the LDW upper reach. The upper reach is a tidally influenced site with a large tide range (~11 ft between MLLW and MHHW). The upper reach also experiences a variety of hydrodynamic and wave forces from river flow, wind-generated waves, and vessel propwash and wakes. Vessels routinely use the upper reach for navigation and the USACE maintains a FNC and Turning Basin for active vessel use. Because of these factors, silt curtains have typically not been used for sediment remediation projects in the LDW because they would interfere with navigation, not be capable of being full-length due to tidal range, and would be anticipated to increase the duration of remedial construction without effectively reducing movement of resuspended sediments. Therefore, silt curtains will not be a required BMP for the upper reach. The specifications will allow the contractor to propose the use of silt curtains if the contractor believes they will help to meet water quality criteria during dredging and placement activities.

11.2.3 Additional Environmental Controls

Available additional environmental controls associated with barge dewatering, haul barge filling and overwater transportation, transloading, transportation to an upland facility, spillage prevention, and decontamination of equipment are described in the following sections.

11.2.3.1 BMPs During Barge Dewatering

For dredge sediment dewatering occurring on haul barges, the dredge return water will be allowed to be discharged back into the LDW within the active dredging work zone. The contractor will be required to equip the barges with appropriate BMPs (e.g., filtering all water prior to discharge to remove suspended solids from the dredge return water) to maintain compliance with water quality criteria.

11.2.3.2 BMPs During Haul Barge Filling and Overwater Transportation

BMPs that will be required to reduce the potential for spillage of dredged material during haul barge filling and overwater transportation include the following:

- Haul barges will be loaded evenly to maintain barge stability.
- Haul barges will be filled to less than 90% capacity to reduce the potential for spillage or overflow.

- Once the barge is loaded and stabilized, it will be inspected for sediment adhered to the outside of the barge that could fall off the barge during transport. Contractor personnel will conduct a visual inspection around the entire barge deck area to remove such sediment before moving the barge out of the dredging site.
- With the exception of dredge return water drainage ports, haul barges will be watertight during all operations, and no unfiltered dredge return water will be allowed to discharge into the LDW in transit to the transload facility.

11.2.3.3 BMPs During Dredged Material Transloading and Transportation to Disposal Facility

BMPs that will be required to reduce the potential loss of dredged material during transloading of dredged materials off the barge at the transload facility, and transport of dredged/excavated material from the transload facility to the approved disposal facility, include the following:

- To prevent dredged material spillage when transloading materials between the haul barge and transload facility, spill aprons will be set up and used to direct bucket spillage back into the barges or onto the uplands and not into the LDW.
- Inside the transload facility, material captured by spill aprons will land on secondary containment areas outside the area typically traveled by trucks or rail cars to avoid tracking material on tires or wheels.
- The bucket swing path from the haul barge to the upland transload facility will not be allowed to occur over open water. The contractor will need to either swing the offloading bucket over the derrick barge, or a "spanning" barge that will capture any spillage from the offloading bucket.
- Visual monitoring will be performed by the contractor to determine if the transport of dry dredged/excavated materials creates a dust concern, and if so, dust suppression controls will be employed (e.g., covering the haul trucks or containers).
- When wet materials are transported over land, haul trucks or rail car containers will be lined or sealed to reduce the chance of sediment or water release during transport.
- Trucks or rail cars will not be overloaded to prevent loss due to spilling (minimum freeboard height of 6 or 36 inches, respectively, will be required to be maintained).
- Truck loading areas will be swept frequently to reduce the probability of truck tires tracking contaminated materials outside of the loading areas.
- The trucks, truck loading area, and the access route will be visually inspected to confirm there is no loss of material from the trucks prior to releasing the truck from the transload facility to public roads.
- Tires and truck or rail car bodies will be cleaned to remove sediment, if necessary, before leaving the site (e.g., dry brushing and tire/wheel washing).

- Containment areas will be designed so that fluids from the transloading operations can be collected separately from other site stormwater.
- The fluid collected from transloading operations will be disposed of with the other waste generated from the site (included with the sediment for disposal) or sampled, treated, and discharged in accordance with approved permits of the transload facility or disposed at a permitted commercial facility.

Exhibit 11-3 depicts examples of offloading/transloading operational controls.

Exhibit 11-3
Examples of Offloading and Transloading Operational Controls

Use of spill apron

Contained landside facility

Spanning barge

Loading of sediment into lined containers

Operations may need to be limited or suspended in the event of high river flows, storms, or high wave conditions at the transload facility that may impact the ability to moor haul barges safely and effectively, transload materials from the haul barges, or prevent potential discharge of dredged materials to the LDW. There is no specific condition (e.g., specific river velocity) that will trigger this contingency because it is impossible to predict the exact set of conditions that would impair operations. However, if conditions appear to pose a threat to meeting environmental protection goals at the transload facility, transload operations will be suspended in coordination with EPA until conditions improve.

11.2.3.4 BMPs for Oil and Other Hazardous Substance Spillage Prevention and Control

For compliance with the National Contingency Plan, the Oil Pollution Prevention regulation (40 CFR Ch. I), and the Oil and Hazardous Substance Spill Prevention and Response (RCW Chapter 90.56), the contractor will be required to prepare and implement a Spill Prevention, Control, and Countermeasure Plan (to be submitted as part of the RAWP), have a spill kit available during all on-water construction activities, and have a marine spill response contractor on call. BMPs to prevent and control spills of oil and other hazardous substances that will be required include the following:

- The contractor will contain all visible floating oils with booms, dikes, oil absorbent pads, or other appropriate means and remove from the water prior to discharge into state waters.
- The contractor will immediately contain all visible oils on land using dikes, straw bales, or other appropriate means and remove using sand, ground clay, sawdust, or other absorbent material, and properly dispose.
- The contractor will temporarily store waste materials in drums or other leak-proof containers after cleanup and during transport to disposal.
- The contractor will dispose waste materials off property at an approved and permitted disposal facility and obtain certificates of disposal.
- Dredge vessel personnel will be trained in hazardous material handling and spill response and will be equipped with appropriate response tools, including oil-absorbent booms or pad, an oil-skimming system, oil dry-all gloves, and plastic bags. If a spill occurs, spill cleanup and containment efforts will begin immediately and will take precedence over normal work.
- The National Response Center (1-800-424-8802), the Washington Emergency Management Division (1-800-258-5990 OR 1-800-OILS-911), and U.S. Coast Guard (206-217-6002) will be notified immediately if a spill occurs.
- The contractor will inspect fuel hoses, oil or fuel transfer valves and fittings, lubrication equipment, hydraulically operated equipment, and oil drums on a regular basis for drips, leaks, or signs of damage, and maintain and store properly to prevent spills into the surface water.

11.2.3.5 Decontamination of Construction Equipment

Decontamination of the dredge and haul barges will be done at the completion of the removal activities and between construction seasons. The haul barges will be swept and pressure-washed (including all portions of the barge where sediment is visually present) such that no sediment or dredge return water is released to the LDW. The remaining sediment and water inside the barge will be managed for off-site disposal, as described in Section 10.2.6.

At the completion of the dredging work and prior to any material placement, the dredging buckets will be pressure-washed over the last haul barge and the wash water will be managed for off-site disposal consistent with the barge dewatering effluents. Similarly, the dredged material haul barges will be decontaminated prior to use for transporting clean placement materials.

After all construction activities are completed, all marine and offloading equipment that handled contaminated dredged material will be required to be decontaminated.

11.3 Quality of Life Considerations

This section describes the activities and measures that will be taken to reduce the effects of remedial construction activities on the local community. While much of the construction will be accomplished with water-based equipment (which is regularly employed throughout the LDW for other industrial activities), the uplands in the vicinity of the upper reach have mixed industrial, commercial, and residential uses (Section 2.3.5). Therefore, the residents in the adjacent neighborhoods, marine users on the LDW, motorists on roads shared with project truck traffic, and workers could potentially be affected.

Any quality of life concerns that arise from the community during construction will follow the Community Outreach and Communications Plan as a reporting vehicle. The plan will be prepared as part of the Pre-Final (90%) RD and will describe not only the required actions to reduce any potential impacts on the community (e.g., residents, businesses, fishers, waterway users) from the remedy implementation, but also a communication/response plan to the community.

11.3.1 Air, Noise, and Light Quality

As part of the specifications to be developed in Intermediate (60%) RD, the contractor will be required to comply with performance requirements for quality of life criteria (i.e., air, noise, and light).

11.3.1.1 Air Quality

Compliance with federal and state air quality requirements will be required during construction activities to protect the surrounding community from diminished air quality.

Air quality performance requirements to be met during construction will be defined in the specifications at Intermediate (60%) RD, following the air emission standards defined in EPA's Tier

System[18] for fossil fuel consumption, to help reduce engine emissions from construction equipment[19].

Examples of BMPs that may be required to limit air quality impacts include the following:

- No truck idling in the neighborhood
- Reduced vehicle speeds
- Revise traffic haul routes or vessel positioning

In addition, dust particles and odors from the project activities will be required to be controlled at all times (including weekends and hours when work is not in progress). Federal and state air quality requirements also establish requirements for dust control. Dust and odor management requirements will include at a minimum the following measures:

- Wetting of excavation areas, unpaved traffic lanes, and soil stockpiles
- Covering truck loads to prevent the escape of dust-bearing materials
- Covering stockpiles with plastic sheeting when loading and stockpiling activities are not occurring (i.e., inactive for a specified period of time) or if nuisance odors are encountered prior to transportation off site
- Cleaning of vehicles leaving the site to remove dirt or dust from wheel treads and exterior
- Using work site controls such as ceasing above-water excavation during high winds or limiting the number and size of excavations open at one time
- Roadways and parking areas will be covered with asphalt, concrete, or gravel (and will be located to the extent possible away from residences)
- Sweeping any paved on-site truck routes, loader paths, loading and stockpiling areas, daily during dry weather, at a minimum.

The contractor's RAWP will be required to identify air quality prevention, mitigation, and control measures to be implemented during construction activities for PSCAA criteria compliance.

11.3.1.2 Noise

The specifications will require the contractor to comply with noise requirements for the cities of Seattle and Tukwila and unincorporated King County areas when working close to residential areas (upland and live-aboard) adjacent to the project site perimeter, to limit to the extent of potential noise impacts to the community. Seattle Municipal Code Chapter 25.08, Tukwila Municipal Code Chapter 8.22, and King County Title 12.86 establish the maximum permissible sound levels for sound sources measured at or within the boundary of a receiving property. Construction noise will be generated from both in-water and upland sources (dredging and excavation of banks and shoreline)

---

[18] https://www.epa.gov/emission-standards-reference-guide

[19] The EPA emission standards for each tier are specific to the type of equipment (on-road vehicles, non-road equipment/engines), the year of manufacture, and the engine power. See Appendix L for more detailed information on EPA's Tier System.

in an already industrial waterway; however, the receiving upland properties and live-aboard residents will be residential and industrial. Specific maximum permissible sound levels associated with various types of equipment used in construction sites are described in Seattle Municipal Code 25.08.425.

Noise-generating construction activities will be limited to normal working hours (between the hours of 7:00 a.m. and 10:00 p.m. for weekdays, and 9:00 a.m. and 10:00 p.m. for weekends and legal holidays) to the extent possible, to reduce potential noise impacts to the community. Seattle Municipal Code, Tukwila Municipal Code, and King County Title 12 noise ordinances set lower sounds levels for any work conducted outside of these hours.

Noise performance requirements to be met during construction will be defined in the specifications at Intermediate (60%) RD based on the most stringent noise ordinance. Examples of BMPs that may be specified to prevent and mitigate noise impacts to the community include the following:

- Reduce vehicle speeds when transiting near residential areas (if applicable)
- Phase work with construction equipment that generates noise
- Turn off engines when equipment is inactive for a period of time

11.3.1.3 Light

It is anticipated that artificial lighting may be required for construction work conducted during winter season (before sunrise [with work starting at 7 a.m.] and after the sun sets around 4:30 p.m.), to accommodate activities during low tides, or to facilitate meeting the construction schedule (i.e., progress of activities within the in-water work window). Although lighting may be considered a nuisance impact, light performance BMPs will be defined in the specifications at Intermediate (60%) RD. For example, the contractor may be required to use light shrouds or barriers to help direct light into the work areas, re-sequence work during the day (if feasible), or reposition lighting equipment to avoid directing light outside of the immediate work area.

11.3.2 Equipment and Material Transportation Through Residential Areas

The majority of dredged and excavated sediments will be barged and offloaded at permitted commercial and/or contractor-provided transload facilities, for loading onto trucks or rail cars for final disposal. Similarly, imported materials for cap and ENR are anticipated to be delivered by barge.

However, to a limited extent, transportation of equipment and materials may be necessary through or near residential areas, causing short-term impacts to the community. Examples would be excavation of certain bank areas using land-based equipment. To the extent feasible, such transportation will be limited to larger arterial roadways that support similar types of traffic. As described in Section 10.2.5, the upper reach project will rely on either established commercial transload facilities or a contractor-provided transload facility with road and/or rail connections designed to support commercial traffic. Candidate truck haul routes (if anticipated to be needed) will be provided in the Intermediate (60%) RD drawings. The contractor will identify the potential haul routes in the RAWP, and will be subject to approval by the Implementing Entity and EPA. Haul routes will be reviewed in coordination with EPA to confirm that they are configured in a manner to reduce impacts to residential neighborhoods to the extent feasible.

11.3.3 Construction Work Hours

The anticipated in-water work hours for the contractor will be from 7 a.m. to 7 p.m., Monday to Friday, and from 9 a.m. to 7 p.m. on Saturdays, for a 6-day per week work schedule. In-water work during the nighttime or on Sundays and legal holidays is not anticipated but may be required to conduct bank excavation activities due to the timing of low tides, or to do occasional work proposed by the contractor to meet the construction schedule and support progress of activities within the in-water work window. EPA coordination and approval will be required for these events. In addition, any in-water work that is conducted during weekends or nighttime will be subject to additional restrictions, as previously described.

11.4 Climate Change Design Considerations

Climate change effects in the greater Puget Sound region and relevant to the LDW include sea level rise; changes in precipitation patterns; and overall hydrological changes. Climate change adaptation generally focuses on evaluating a system's vulnerability to climate change and implementing adaptation measures, when warranted, so that the remedy continues to remain effective at meeting the ROD objectives (EPA 2015).

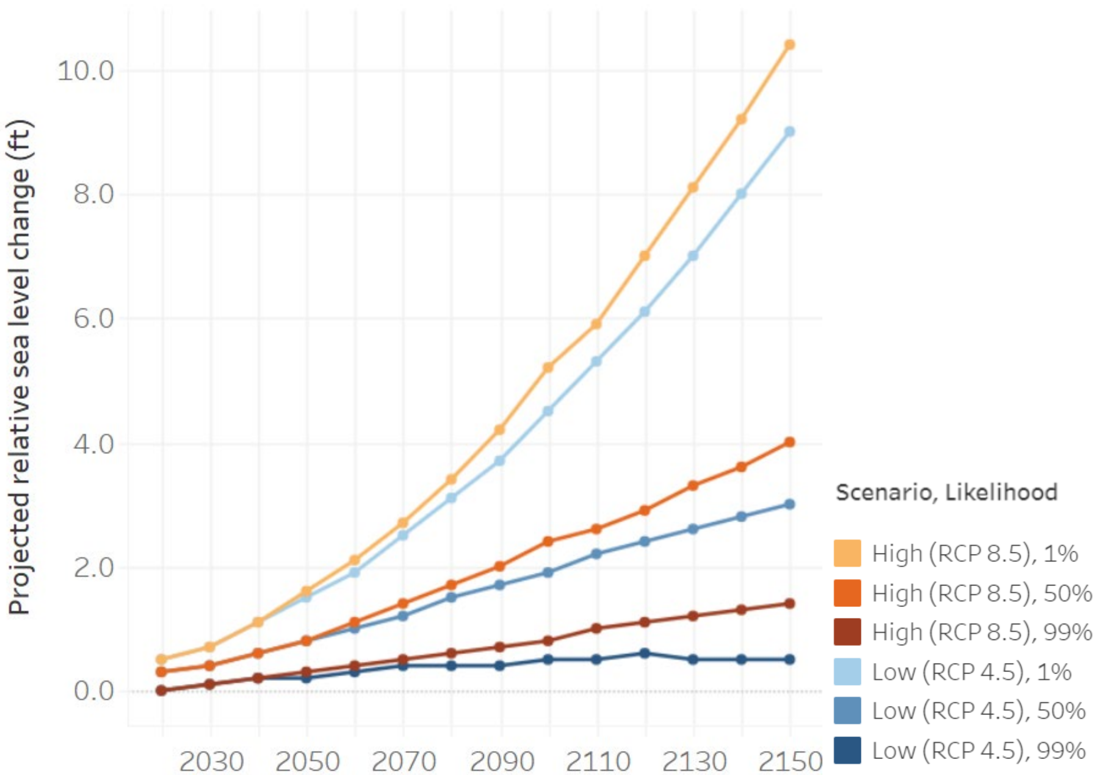
11.4.1 Sea Level Rise

Climate change is expected to increase sea levels over the next few hundred years (CIG/UW 2017). An increase in mean sea level will correspond to an increase in design water levels at the upper reach due to tidal influence; however, not all components of the RD are anticipated to be affected by an increase in design water levels. For example, dredging will not be affected by the increase in water depth, and caps and ENR layers are designed assuming constant or tidal immersion.

In the future, sea level rise will increase the water depths within the upper reach. The projected changes in sea level have been assessed in accordance with Ecology guidance. A report prepared for the Washington Coastal Resiliency Project (WCRP) in 2018 provided an assessment of projected sea level rise and the associated hazards for Washington State. The WCRP report provides updated projections for sea level rise that are more comprehensive than past estimates, taking into consideration recent research, land movement, and greenhouse gas emissions. Greenhouse gas emission projections depend on a variety of factors related to human behavior. Therefore, probabilistic projections for sea level rise have been made based on both low and high greenhouse gas scenarios.

Climate projections are made for two greenhouse gas emissions scenarios in the WCRP report: Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. RCP 4.5 is a low estimate in which greenhouse gas estimates stabilize by mid-century and decrease thereafter. RCP 8.5 is a high scenario in which there is a continued increase in greenhouse gasses until the end of the twenty-first century (Mauger et al. 2015). The Washington Coastal Network utilized the data presented in Miller et al. (2018) to generate visualization tools to projected sea level rise applicable to various coastlines across Washington. Exhibit 11-4 shows the projected sea level rise for various potential scenarios for the upper reach. The exhibit presents the projects for RCP 4.5 and RCP 8.5 for the 1%, 50%, and 99% likelihood of occurrence. While there is no industry standard for the application of sea level rise projections, other projects in the Puget Sound have incorporated the 50% central estimate for the design of site elevations. Based on the projections and using the 50% central estimate, the relative sea level is predicted to rise between 1.9 to 2.4 ft by 2100 (Miller et al. 2018).

Exhibit 11-4
Sea Level Rise Projections for the LDW



Source: https://wacoastalnetwork.com/research-and-tools/slr-visualization/

11.4.2 Hydrodynamics

As described in the RDWP, additional modeling of climate change on future hydrodynamics is not necessary as part of RD. First, propwash velocities and vessel wakes control cap design because they are much higher than velocities due to river flows or wind-generated waves, although propwash velocities will reduce with SLR. Second, ongoing water management practices at the Howard Hanson Dam effectively control most peak river flows in the Duwamish River (USACE 2014).

Propwash forces on the riverbed are expected to be lower with sea level rise due to the larger propeller clearance as water depths increase. Wake forces are not expected to change with sea level rise because wake heights are not expected to change.

USACE evaluated how climate change could impact hydrology and water management operations on the Green River, and what adaptations might be feasible at Howard Hanson Dam to accommodate those impacts (USACE 2014). The report concluded that the current water control plan at Howard Hanson Dam is somewhat resilient to climatic shifts and that flexibility inherent in the reservoir regulation could be adapted to further accommodate climate changes. Floodplain studies performed by King County demonstrate that the Interstate 5 Green River crossing restricts the ability of high flows and floodwaters to affect downstream areas north of this restriction even when considering sea level rise (King County, reference pending).

11.4.3 Sediment Load

Uncertainties in estimates of sediment load were evaluated as part of the RI/FS process. Climate change impacts and land use changes of upstream areas in the Green-Duwamish watershed may affect the relative and total sediment contributions to the LDW. Higher flows in the Green River may result in higher sediment loads in the river, and therefore, a higher potential for deposition over the MNR areas. As a result, the MNR process may be accelerated. Studies by LDWG indicate that higher flows are not expected to increase overall erosion in the LDW (QEA 2008).

Climate change effects on sediment load do not affect the design of remedial action because the ROD defines what remedial technologies are applicable for the present site conditions. No further modeling of these effects on sediment loads is planned due to the infeasibility of predicting changes to sediment load that have many contributory factors (e.g., upland development, agricultural practices, erosion, dam operations, stormwater discharges).

11.4.4 Design for Climate Change Adaptability

As part of the design process, an assessment was performed to evaluate how long-term changes in sea level and corresponding water depths would influence the remedy. The RD allows the remedy to adapt to long-term climate change scenarios. This section the presents the assessment for the key design elements and describes how those elements are adaptable to climate change.

Dredging Remedial Action Adaptation

Dredging RD footprints (horizontal and vertical extents) are not affected by sea level rise because the dredging minimum removal extents are developed based on the design chemistry dataset, PDI geotechnical engineering data, and engineering considerations, which are based on current, not future, conditions for design.

Capping and ENR Remedial Action Adaptation

As part of the cap erosion protection evaluation, potential long-term changes in water depths were assessed. As described in Appendix H, the proposed interim sediment cap in Area 18 is expected to be stable under long-term water level changes. Future sea level rise conditions are not expected to increase the stable sediment size required for the cap armor stone to resist propwash or wind- and vessel-generated wave forces. As the depths within the waterway will increase, bottom velocities from propwash forces will decrease, resulting in a decrease in needed stable sediment size. This conclusion for the interim sediment cap in Area 18 is also applicable to other caps, should they be determined necessary during subsequent stages of RD.

Vessel wake heights are not expected to increase with the addition of sea level rise to the waterway, because travel speeds are expected to remain similar to current day, and the relative change in water depth is not expected to substantively change the types of vessels that transit the LDW. Therefore required stable sediment sizes for future sea level rise conditions are not expected to increase. However, with sea level rise, higher bank elevations will be subject to wakes. Thus, where banks are to be capped, the cap will extend to existing top of bank using a substrate that will resist current-day and future vessel wakes considering higher water levels.

ENR remedial action is also not expected to be impacted by future sea level rise for the same reasons as capping remedial action.

Habitat Elevations Adaptation

Habitat restoration elevations per the ROD state that habitat areas (above -10 ft MLLW or as determined by EPA) will be restored to their pre-dredging elevations by backfilling dredged areas with habitat suitable materials (ROD Section 13.2.1.1; EPA 2013). Increase in water depths due to sea level rise would not impact the RD because the required backfilling will be performed in habitat areas. Sea level rise would essentially raise the MHHW elevation, which may also raise the lower elevation band of habitat area. Such changes in habitat will occur globally, and potential future mitigation actions are outside the scope of the CERCLA action.,.

Bank Stability Adaptation

Remedial actions that affect bank areas will be designed to address long-term bank stability, including geotechnical stability and bank erosion stability. From a climate change adaptation standpoint, the potential vertical top elevation of bank armoring (in required areas) will anticipate predicted sea level rise elevations and will be designed to top of bank to provide erosion protection at the future 100-year sea level rise elevation.

11.5 Green Remediation

According to the EPA Office of Solid Waste and Emergency Response *Superfund Green Remediation Strategy* (EPA 2010), "…green remediation is generally recognized as a major step in maximizing the environmental outcome of a contaminated land cleanup…", by incorporating specific strategies into remedial actions that reduce their environmental footprint to achieve greater net environmental benefits. A *Green Remediation Evaluation and Implementation Approach* (Appendix L) has been developed for the upper reach remedy to evaluate impacts of remedy construction activities, including sediment dredging and excavation, debris removal, sediment offload/transload, sediment upland transportation and off-site disposal, material placement, and structural work.

11.5.1 Green Remediation Objectives and Approach

As described in the RDWP, the purpose of the Green Remediation Evaluation and Implementation Approach is to:

- Establish the project's environmental footprint for the sediment remedy presented in the BODR, through the five core elements identified in the *Superfund Green Remediation Strategy* (EPA 2010): air, water, materials and waste, energy, and land and ecosystems.
- Identify potential applicable greener construction activities, technologies, and practices that could be applied to the extent practicable during the sediment remedy implementation (e.g., dredging, sediment transloading, transportation, and disposal, material placement, habitat restoration, and structural work), in an effort to reduce the project's environmental footprint (consistent with the EPA Region 10's *Clean and Green Policy* [EPA 2009]), while still achieving the ROD remedial action objectives and protectiveness requirements in a timely manner.

The five core elements identified in the *Superfund Green Remediation Strategy* (EPA 2010) and used for the *Green Remediation Evaluation and Implementation Approach* (Appendix L) are summarized as follows:

- **Air and Atmosphere:** Reduce emissions of air pollutants, including greenhouse gases.
- **Water:** Reduce water use and protect water quality.
- **Energy:** Reduce energy use and support the use of renewable energy.
- **Materials and Waste:** Reduce waste generation and the use of virgin materials.
- **Land and Ecosystems:** Protect land resources and ecosystems near the site.

The *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012c) was used in Appendix L to develop the framework for conceptually quantifying the environmental footprint associated with remedial actions (cleanup activities), understanding the remedy components with the greatest influence, and determining key green remediation metrics for each of the above green remediation core elements. Additional EPA green remediation guidance and policy documents were also reviewed and considered in the application of sustainable cleanup activities, technologies, and practices to a greener and sustainable upper reach sediment remedy to the extent practical (see Appendix L).

11.5.2 Construction Activities Required for the Sediment Remedy

Construction activities associated with the upper reach remedy are the baseline for determining the project's environmental footprint, to comprehensively include the work required to implement, understand the sediment remedy components with the greatest influence, and appropriately represent the environmental impacts and effects the project may generate on the environment. It is important to note that the construction activities and the development of the environmental footprint presented in Appendix L are based on Preliminary (30%) RD criteria and assumptions. However, the quantification of the Preliminary (30%) RD environmental footprint is a high-level, conceptual evaluation, based on current available design information, assumed contractor equipment, and past engineering experience with similar projects.

The anticipated construction activities needed to implement the sediment remedy can be classified as primary (major construction activities) and secondary (minor construction activities). Both of these are conducted either within or outside of the project site but directly contribute to the project's environmental footprint. Additional activities, referred to as ancillary, are other activities that are indirectly required or associated with the sediment remedy implementation, but are sourced elsewhere and not dependent on the remedy itself; therefore, they are not considered applicable activities to the project.

The detailed construction activities associated with the upper reach sediment remedy for the purposes of the green remediation evaluation are described in Appendix L.

11.5.3 Application of Green Remediation into Remedial Design

Consistent with the 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012c), green remediation metrics are designed to 1) reflect parameters that a remedy project team has a relatively direct ability to change; and 2) encourage practices that would result in favorable changes to the metric values. The following metrics were evaluated in Appendix L for the five green remediation core elements associated with the upper reach sediment remedy:

- **Core Element 1 - Air emissions.** Air emissions were calculated for eight air constituents: hydrocarbons, volatile organic compounds, carbon monoxide, nitrogen oxides, particulate matter less than 10 and 2.5 microns in diameter (PM_{10} and $PM_{2.5}$, respectively), sulfur dioxide, and carbon dioxide. [20]

- **Core Element 2 - Use of water.** Consumption of water during construction activities (such as dust control, equipment decontamination, additional uses at transloading facilities) was considered.
- **Core Element 3 - Use of materials and waste generation.** Raw materials (imported sand, gravelly sand, gravel, and cobble for backfill, RMC, ENR, and capping activities), recycled materials, and waste materials (dredge sediment, debris, removed piles/structural items) associated with the upper reach sediment remedy were quantified.
- **Core Element 4 - Use of energy.** Total fuel-based energy consumption (diesel fuel) to power engines and equipment, facilitate transport activities, and run operations associated with the upper reach sediment remedy implementation were accounted for.
- **Core Element 5 - Protection of land and ecosystems.** A qualitative assessment on safeguarding land/ecosystems and site preparation/land restoration was conducted.[21]

The above metrics establish the project's conceptual environmental footprint based on the anticipated cleanup construction activities, so that the most applicable greener construction activities, technologies, and practices, through BMPs, can be identified at the Intermediate (60%) RD step and applied to the extent practicable to reduce the impacts of the sediment remedy. Appendix L presents a comprehensive list of potential BMPs that might be applicable to the five core elements in relation to the upper reach sediment remedy and its anticipated construction activities, consistent with the BODR and the Preliminary (30%) RD.

The listed BMPs will be further assessed in Intermediate (60%) RD for availability of more advanced technologies and materials, for feasibility and implementability of greener practices into the sediment remedy, and in consideration of procurement restrictions. To the extent that specific BMPs will be required, these BMPs will be incorporated into the project specifications, which will be developed for submittal with the Intermediate (60%) RD deliverable. The contractor will have inherent motivation to select other specific BMPs listed in Appendix L in cases where such BMPs will increase efficiency and reduce cost, and therefore, have an appropriate return on investment that justifies their use.

---

[20] Carbon dioxide is also a key greenhouse gas, along with methane and nitrous oxide which are the largest greenhouse gas contributors. Appendix L, however, accounts for methane and nitrous oxide in the CO_2-eq total.

[21] Specific design measures to offset aquatic habitat modifications that may be incorporated into the LDW upper reach sediment remedy to the extent practicable are presented in Section 11.6, in compliance with Section 404 of the Clean Water Act and Section 7 of the Endangered Species Act.

11.6 Habitat Considerations and Evaluation

Habitat within the LDW will be considered and evaluated during all phases of RD. As described in Section 2.3.11, existing habitat types in the LDW based on elevation ranges include the following:

- Deep subtidal: deeper than -10 ft MLLW
- Shallow subtidal: -10 ft MLLW to -4 ft MLLW
- Intertidal: -4 ft MLLW to +4 ft MLLW
- Upper intertidal: +4 ft MLLW to +11.3 ft MLLW

These different habitat types provide specific functions to aquatic species, and the value of each habitat type differs depending on the functions provided. The most valuable habitat is provided in the upper intertidal, intertidal, and shallow subtidal zones (i.e., -10 ft MLLW and shallower) as detailed in Section 11.6.3.1.

The ROD defines "habitat areas" as all areas with elevations between -10 ft MLLW and the MHHW elevation of +11.3 ft MLLW to provide design requirements for remedial activities that occur within those elevations. As such, this Preliminary (30%) RD considers and applies the habitat specific ROD design requirements to remedial activities that occur within the ROD-defined "habitat areas". These design requirements will be further refined through the Intermediate (60%) RD and Pre-Final (90%) RD. Additionally, the impact of remedial activities to all habitat types, including the ROD-defined "habitat areas", will be evaluated during Intermediate (60%) RD and Pre-Final (90%) RD to comply with Section 404 of the Clean Water Act and Section 7 of the Endangered Species Act. The result of the habitat evaluation will determine if the remedial activities are expected to improve or degrade habitat conditions relative to existing conditions.

The remainder of this section includes details about the following:

- Approach for addressing potential impacts of remedial activities on habitat
- Design considerations for the ROD-defined "habitat areas"
- Description of the habitat evaluation that will be used to assess remedial impacts to all habitat types, including the ROD-defined "habitat areas"

11.6.1 Approach

The approach to considering and evaluating habitat during the RD is as follows:

- Identify areas where remedial activities are expected to occur in ROD-defined "habitat areas" and consider the ROD habitat design requirements during RD for these areas (Section 11.6.3).
- Determine a method for evaluating potential remedial impacts to all habitat types, including ROD-defined "habitat areas" (Section 11.6.3).
- Demonstrate that the remedial activities are consistent with the Clean Water Act Section 404(b)(1) and Section 7 of the Endangered Species Act, including consistency with the

USACE and EPA approach for avoiding, minimizing, or, when adverse impacts are unavoidable, mitigating for adverse impacts to the aquatic environment. This demonstration will be made by conducting the habitat evaluation during the Intermediate (60%) design process and include results as part of the design submittal in the Draft Clean Water Act Section 404(b)(1) evaluation. Use the results of the habitat evaluation to support the evaluation of threatened and endangered species in the Draft Biological Assessment.
- Update the habitat evaluation as needed during the Pre-Final (90%) RD and include results as part of the design submittal in the Final Clean Water Act Section 404(b)(1) evaluation. Use updated results to support the Final Biological Assessment.

11.6.2 Design Considerations for Remedial Activities in ROD-Defined Habitat Areas

Figure 11-1a shows where remedial activities are expected to occur within ROD-defined "habitat areas." Figure 11-1b includes the following information important for understanding existing conditions and the context of the ROD-defined "habitat areas":

- Potential clamming areas as described in Section 2.3.11
- Existing restoration areas as described in Section 2.3.11
- Shoreline condition
- Existing bank vegetation

The ROD identifies the following design elements that should be considered during RD for remedial activities that occur within the ROD-defined "habitat areas:"

- Restore pre-dredge elevations using suitable habitat materials. Different substrate types are naturally present throughout the upper reach in various habitat types, which are used by a variety of species.
- The RD will specify substrate that balances targeted functions (providing substrate that is as similar as possible to pre-construction conditions) and constructability/environmental protection during construction (minimizing fines content to reduce turbidity to the extent practicable).
- Coordination with EPA will occur in the Intermediate (60%) and Pre-Final (90%) RD to evaluate proposed habitat substrate, recognizing that the post-construction surface substrate will equilibrate over time to the naturally deposited sediment grain size regardless of the selected substrate.
- Use suitable habitat material as the uppermost layer of caps and for ENR.
- Caps in intertidal clamming areas must include a minimum 45-cm (1.5-ft) clam habitat layer.

EPA will determine whether the elevations and substrate materials presented in this Preliminary (30%) RD are consistent with habitat requirements. Materials used for caps, ENR, and backfill placement will be further evaluated in Intermediate (60%) and Pre-Final (90%) RD submittals to confirm habitat suitability in consultation with EPA. Based on the habitat material used at other sites in Puget Sound, suitable material is expected to be a mix of sand and gravel as described in Section 10.5.1. During Intermediate (60%) RD, details and specifications will be developed for habitat elements for the reestablishment of targeted habitats.

Measures described above to backfill dredged habitat areas with appropriate material and place appropriate material over cap armor and as ENR material have been incorporated into the Preliminary (30%) RD to the extent practicable. Using these strategies, the remediation is expected to avoid the need for mitigation. This expectation will be confirmed by implementing the habitat evaluation described in Section 11.6.3.

11.6.3 Habitat Evaluation

An evaluation of potential impacts to all habitat types, including ROD-defined "habitat areas," from implementation of remedial activities will be conducted to comply with the Clean Water Act Section 404 and Section 7 of the Endangered Species Act. The habitat types and method that will be used for the evaluation are described below.

11.6.3.1 Habitat Types Based on Elevation Ranges

Existing habitat types in the LDW include upper intertidal (+4 ft MLLW to +11.3 ft MLLW), intertidal (-4 ft MLLW to +4 ft MLLW), shallow subtidal (-10 ft MLLW to -4 ft MLLW), and deep subtidal (deeper than -10 ft MLLW). These elevation ranges will be used for the habitat evaluation. The elevation range included in the ROD for "habitat areas" (i.e., shallower than -10 ft MLLW) is consistent with the upper intertidal, intertidal, and shallow subtidal habitat types. These shallow water habitats are the most valuable based on the importance of the 0- to 10-ft water depth range to aquatic species, including salmonids. Additionally, this depth range is used in other regulatory settings in the region to define the most valuable habitat.

Shallow water habitats having gentle intertidal gradients and lower velocities tended to support higher Chinook salmon densities in a juvenile Chinook salmon study conducted in the LDW (Ruggerone et al. 2005). Additional studies outside of the LDW also found shallow water (i.e., less than 6.5 ft deep) to be important for the growth and survival of juvenile salmon, especially subyearling Chinook salmon, because these areas tend to have low velocities and a shallow slope and are close to shoreline riparian areas (Tiffan et al. 2006; NMFS 2005; Fresh 2006; Everest and Chapman 1972; Hillman et al. 1987; and Johnson et al. 1992). (Six to 10 ft of water depth is also important for juvenile salmon for rearing and migration, as juvenile fish are expected to move to deeper water as they grow. The Oregon Department of Fish and Wildlife (ODFW 2005) found that sites with an average depth between 2.1 and 3.0 m (7 to 10 ft) had significantly higher catch per unit of effort of Chinook salmon than deeper sites. At low water, the -10 ft MLLW and shallower habitat range will provide 0-10 ft of water depth. Up to 10 ft of water depth is not only important for meeting juvenile salmon habitat requirements but also for supporting all aquatic species.

Nearshore shallow water habitat is the most biologically productive zone of a large estuarine river. This productivity is important in providing a food base for aquatic species throughout the LDW. Intertidal marsh habitat provides refuge as well as foraging and rearing habitat for benthic invertebrates and fish, including juvenile salmonids (Battelle et al. 2001). In addition, intertidal marshes provide important foraging and rearing habitat for many bird species, including great blue heron, killdeer, and marsh wrens. Intertidal mudflats serve as sources of nutrients for primary producers, and provide food and habitat for benthic invertebrates, fish, shorebirds, and aquatic mammals (Battelle et al. 2001). Clams are also present in intertidal habitats in the LDW (Windward 2004).

In the LDW, habitat restoration projects used for Natural Resource Damage settlements and other purposes have focused on restoring intertidal habitats (between elevations +12 ft and -4 ft MLLW), including marsh habitat, as these are the most valuable habitat types as determined by the Elliott Bay Natural Resource Trustees. In addition, NMFS and USFWS use -10 ft MLLW as the lower limit of the shallow water zone as part of the Puget Sound Nearshore Calculator that is being used to evaluate impacts to threatened and endangered species as part of the Endangered Species Act consultation process.

Overall, the upper intertidal, intertidal, and shallow subtidal habitat types defined for the LDW (i.e., areas shallower than -10 ft MLLW) include the most valuable intertidal habitat types within the LDW and include the water depth band that has been shown to be the most important for juvenile salmon, particularly Chinook salmon, and other aquatic and semi-aquatic species, including benthic invertebrates (e.g., clams), fish, and shorebirds. These shallow water habitat types also include a depth range that is consistent with habitat areas identified as part of other regional regulatory processes, including Natural Resource Damage Assessment and Endangered Species Act. Therefore, the habitat evaluation will use the upper intertidal, intertidal, shallow subtidal, and deep subtidal habitat types to evaluate potential impacts from implementation of the remedy.

11.6.3.2 Habitat Evaluation Method

The method that will be used for the evaluation is Habitat Equivalency Analysis (HEA). HEA is an accounting technique that will be used to compare habitat functions before and after remediation in areas where active remediation is expected to occur. A key benefit of using HEA is that it allows for a holistic sitewide assessment that can integrate all three reaches of the LDW. A separate habitat evaluation will be conducted for each reach during RD and the results will indicate either a habitat deficit or benefit at the reach level. This allows for benefits in one reach to be used to offset unavoidable impacts in another reach and identify if there is any net site-wide mitigation need.

HEA is a generalized method that can be used in any type of habitat, including freshwater rivers and streams, salt marshes, seagrass beds, and coral reefs. The main assumption associated with HEA is that a one-to-one tradeoff between habitat functions lost and gained is acceptable (NOAA 2000). HEA normalizes different habitat types (e.g., intertidal marsh, shallow subtidal, deep water) to a "gold standard" using relative habitat values. Relative habitat values are values between 0 and 1 that are based on the habitat functions provided by the habitat type relative to the "gold standard." For example, degraded habitat is given a lower value (0.1) than the fully-functioning, high-quality habitat (1.0).

Overall, the habitat evaluation using HEA will include a comparison of pre-remediation and expected post-remediation conditions in areas where remedial activity is expected to occur. This evaluation will be completed for all areas where remediation is expected to occur, including the ROD-defined habitat areas. The comparison will provide the basis for evaluating potential impacts of the remediation on habitat to confirm if the application of ROD-required design elements within habitat areas results in a self-mitigating remediation project. The habitat evaluation will be included as part of the Clean Water Act Section 404(b)(1) evaluation, and results will be included in the Biological Assessment and used as part of the Endangered Species Act consultation described in Section 3.5. The Draft Section 404(b)(1) Evaluation and Draft Biological Assessment will be submitted as part of the Intermediate (60%) RD submittal, and final versions of both documents will be submitted as part of the Pre-Final (90%) RD submittal.

The design for the upper reach will seek to maintain net habitat value and avoid the need for mitigation. Additionally, it is anticipated that the future design for the middle and lower reaches will also seek to avoid the need for mitigation to the extent possible, which will be confirmed by conducting the same habitat evaluation for middle and lower reaches. The resulting habitat debits or credits will be determined for each reach. The intent is to use potential credits generated in one reach to offset potential impacts estimated in another reach, such that the overall need for mitigation will be avoided across all three reaches of the LDW. Because the upper reach is the first project to be designed and constructed, it is the intent of the upper reach design to result in net neutral or positive habitat credit.

If it is determined that the existing habitat value cannot be maintained or improved after considering all three reaches of the LDW, a Draft and Final Compensatory Mitigation Plan will be included in the RD submittals for the lower reach.

12 Site Access

Property acquisition, site access agreements, leases, or easements may be needed at properties where remedial activities will be implemented, or for off-site staging areas that may be required for the contractor's material, equipment staging, and shore access during construction. Agreements may also be needed when remedial activities have the potential to disrupt commercial businesses. Coordination with property owners or lessees will occur during Intermediate (60%) and Pre-Final (90%) RD to accommodate construction near infrastructure and in shoreline areas where upland equipment access is required. Depending on the owner, the nature and duration of the access, and the resulting remedy, written agreements or other legal documentation (e.g., leases, easements, deed restrictions) may be required. Section 12.1 identifies the property locations and owners where site access agreements are anticipated to be necessary. The design team will develop a Draft Site Access Plan in the Pre-Final (90%) RD, and a final Site Access Plan in the Final (100%) RD.

12.1 Site Access Considerations

The upper reach consists mostly of publicly owned aquatic land (Port of Seattle and State of Washington) but includes some privately owned submerged portions of adjacent upland parcels. Access agreements with the Port of Seattle and the State were not needed for sampling during the PDI activities and assumed not to be necessary for construction activities for Port- or State-owned portions of the LDW Superfund Site. For construction, it is anticipated that access to waterway and upland properties owned by LDWG parties will be readily approved, and site access agreements with adjacent property owners will be attainable if needed to facilitate remedy construction. Access agreements are anticipated to be required with private owners of waterway or adjacent property if such areas are determined necessary to accomplish remedy construction. A summary of anticipated site access need by RAA is provided in Table 12-1.

Table 12-1
Anticipated Site Access Needs by RAA

RAA	Property Owner and Adjacent Property Owner (if applicable)[1]	Access Agreement Needed?[2]	Upland Site Access Anticipated?
1	Port of Seattle	No	No
2/3	Port of Seattle	No	No
4/5	Port of Seattle King County	No[3]	No
6	Port of Seattle	No	No
7	Port of Seattle	No	No
8	Port of Seattle King County	No[3]	No
10	Port of Seattle King County	No[3]	No
11	Port of Seattle King County	No[3]	No
12	Port of Seattle	No	No
13	Port of Seattle South Park Marina Ltd	Yes	Yes
14	Port of Seattle	No	No
15/16	Port of Seattle	No	No
17	Port of Seattle	No	No
18	Port of Seattle, Boeing[4]	Yes	Yes
19/20	Port of Seattle Boeing	Yes	Yes
21	Port of Seattle	No	No
22	Port of Seattle Centerpoint Properties	Yes	No
23	Port of Seattle Boeing	Yes	Yes
24	Port of Seattle Centerpoint Properties	Yes	Yes
25	Port of Seattle	No	No
26	Port of Seattle Centerpoint Properties	Yes	Yes
27	Container Properties LLC	Yes	Yes
28	Boeing	Yes	No
29	Port of Seattle Boeing	Yes	Yes
30	Port of Seattle	No	Yes

RAA	Property Owner and Adjacent Property Owner (if applicable)[1]	Access Agreement Needed?[2]	Upland Site Access Anticipated?
31	Port of Seattle	No	Yes
32	Washington State DNR Boeing	Yes	Yes
33	Washington State DNR Boeing	Yes	Yes
34	Washington State DNR Boeing	Yes	Yes
35	Washington State DNR Boeing	Yes	Yes

Notes:

1. For areas located within the LDW (which is in Port of Seattle ownership up to the Turning Basin and Washington State Department of Natural Resources south of the Turning Basin), the secondary property owner listed is the adjacent upland property. Adjacent property owners are listed when the RAA is within 50 ft of the property.
2. It is assumed that properties will require an access agreement when the RAA is within 50 ft of the property.
3. King County owns the South Park Bridge, which crosses the waterway. Although an access agreement is not needed for remediation in RAAs adjacent to the bridge, it is expected that some notification will be required to inform King County Roads prior to remedial construction
4. The Port of Seattle owns an upland sliver property adjacent to the north portion of Area 18.

DNR: Department of Natural Resources
RAA: remedial action area

12.2 Permitting for Site Improvements

The Preliminary (30%) RD does not anticipate implementing any site improvement work that would require permitting. Examples would include developing new buildings not located within or adjacent to the LDW Superfund Site to support construction management or transloading operations at a LDWG-provided upland staging area.

In its review of Preliminary (30%) RD, if EPA identifies site improvement actions that fall outside of CERCLA authority and that require a permit, the Draft Permitting and Site Access Plan in the Pre-Final (90%) RD will identify required permit(s) and the schedule to obtain the permit(s).

13 Preliminary Construction Sequencing and Schedule

13.1 Construction Sequencing

Cleanup construction activities will be sequenced to accommodate logistics and reduce release of contaminants, generally beginning with contaminated debris removal (i.e., demolition and removal of creosote-treated materials) followed by intertidal excavation and subtidal dredging. Capping, backfill, and ENR will be sequenced to occur after removal actions are completed to limit residual contamination and reduce risk of recontamination of previously cleaned up areas. In general, work will be required to start at the upstream end of the upper reach and work downstream to reduce risk of recontamination of cleaned up areas. Construction and post-construction monitoring and institutional controls will be implemented to verify the protectiveness of the remedy.

Certain sequencing requirements will be specified (e.g., Owner approval of dredge areas prior to any backfilling; access time periods for specific properties). However, the specific sequencing of the construction will be defined in the contractor's RAWP and will be dependent on (among other things) the transloading proposed by the contractor. Assuming commercial transloading at either facility identified in Section 10, construction sequencing is anticipated to be generally as follows:

1. Development and approval of contractor's RAWP
2. Notifications to property owners, Tribes, public, U.S. Coast Guard, and any agency-required notifications have been completed in accordance with ARARs and permits
3. Mobilization and setup of temporary facilities, including transloading area
4. Procurement and testing of clean placement materials
5. Pre-construction survey and conditions documentation of structures (photographs/video)
6. Boundary area documentation sampling (pre-construction)
7. Removal of piling and debris from dredge areas
8. Temporary removal and disconnection of in-water structures and utilities to allow equipment access as needed
9. Dredging and excavation (generally upstream to downstream), including in-water transport, transload, upload transport, and disposal of dredged materials at an approved disposal facility
10. Dredging acceptance surveys and contingency re-dredging, if determined to be necessary based on post-dredge survey results
11. Post-dredge confirmatory sampling and contingency actions, if needed
12. Material placement: post-dredge backfilling, RMC placement, ENR placement, and capping
13. Post-placement acceptance surveys
14. Reinstallation of temporarily removed in-water structures and utilities
15. Pre-final and final inspections
16. Corrective measures (if needed)
17. Demobilization and site cleanup

Multiple activities may occur concurrently, such as dredging in downstream areas while material placement is occurring in upstream areas where dredging has been verified to be complete. The contractor will maintain an up-to-date detailed schedule of activities in accordance with the specifications.

13.2 Construction Schedule

Remedial construction of the upper reach will proceed following source control sufficiency determinations, as described in the RDWP. In-water construction activities will occur during in-water work windows designated for the LDW (to be determined by EPA but anticipated to be from approximately October 1 through February 15, or an approved extension) that will be set to protect threatened and endangered species under the Endangered Species Act. Construction activities will be coordinated with the Muckleshoot Indian and Suquamish Tribes to reduce impacts on tribal fishers. Remedial construction for the upper reach is anticipated to require two construction seasons based on the Preliminary (30%) RD production rates for dredging (Section 10.2.4) and material placement (Section 10.5.6), and as defined by the in-water work windows. A third construction season may be required depending on the sequencing of work elements and overall production rates. Production rates and the anticipated construction schedule will be refined in the Intermediate (60%) RD.

The conceptual preliminary construction schedule shown in Figure 13-1 identifies the major phases of construction; a detailed preliminary construction schedule in Gantt chart format will be developed at Pre-Final (90%) RD based on experience estimating construction production rates for similar work at other sites, assumptions regarding contractor and crew and equipment resources that may be dedicated to the project, and engineering best professional judgement.

14 Quantity Calculations and Opinion of Probable Cost

This section provides information on quantity calculations and the opinion of probable cost for the Preliminary (30%) RD.

14.1 Quantity Calculations

Quantity calculations for dredging and material placement (including backfill, RMC, ENR, and cap materials) are discussed below and summarized in Table 14-1.

Dredge volumes were calculated for each RAA with AutoCAD Civil3D software based on the design dredge plan (i.e., dredge prism) included in Appendix D (Preliminary Drawings). The dredge prism volume is measured by developing a triangulated irregular network (TIN) surface of the required dredge prism (including side slopes) and calculating the cut and fill quantities between the dredge prism TIN surface and the TIN surface of the recent bathymetric and topographic survey basemap. The volume of the overdredge allowance was computed by using the area of the dredge prism boundary, including side slopes, and multiplying that area by the 1-ft overdredge allowance.

Following the completion of all required dredging, Preliminary (30%) RD has assumed that one additional contingency re-dredging pass will be conducted over a portion of the RAA dredge footprint to remove generated dredge residuals above a threshold concentration (that will be developed as part of the CQAP post-dredge confirmation sampling plan) and remove missed inventory. For costing purposes, as described in Appendix M, Preliminary (30%) RD assumes that 15% of the required dredge area will be re-dredged by 1 ft (which includes 6 inches of overdredge allowance) to address generated residuals, and 20% of the required dredge area will be re-dredged by 2.5 ft (which includes 6 inches of overdredge allowance) to remove missed inventory.

RMC, ENR, and cap material placement quantities were developed using the Preliminary (30%) RD assumed placement thicknesses and overplacement allowance over each respective placement area (generated via AutoCAD). The assumed placement thicknesses used for costing purposes in Appendix M are as follows:

- RMC is assumed to be applied at a minimum 6-inch thickness, with a 3-inch maximum overplacement allowance, over 100% of the dredge area that does not receive backfill or a cap. RMC placement footprint includes side slope areas and an additional 10% footprint (approximately equivalent to a 10-ft buffer surrounding the dredge area) in specific RAAs (as shown in the Preliminary [30%] Design Plans [Appendix D]).

- ENR is assumed to be applied at a minimum 6-inch thickness, with a 6-inch maximum overplacement allowance in specific RAAs (as shown in the Preliminary [30%] Design Plans [Appendix D]). ENR quantity assumes a placement footprint that includes a 10-ft buffer around the planned ENR placement area.

- Engineered capping is applied to limited portions of Area 18 (as shown in the Preliminary [30%] Design Plans [Appendix D]) and outside of the FNC. The engineered cap is assumed to consist of two layers: chemical isolation layer (assumed to be a sand/ZVI mix; 1.5 ft thick with a 6-inch maximum overplacement allowance) and erosion protection/filter layer (mixed cobble-sized aggregate and gravel; 6 inches thick with a 6-inch maximum overplacement allowance). A surficial 1.5-ft layer for clam habitat substrate (e.g., gravelly sand) is assumed to be placed above the engineered cap.

Backfill placement is intended to restore habitat areas to restore pre-construction elevations and to flatten temporary steeper dredge cuts (e.g., along the Boeing Plant 2 EAA). For Preliminary (30%) RD, all dredge areas located outside of the FNC and above elevation -10 ft MLLW, are assumed to be backfilled and integrated with habitat material placement in intertidal areas as appropriate. Backfill volumes are dependent on the final dredge cut surface and may not exactly match the pre-dredge elevations due to equipment placement accuracy and geotechnical properties of the placement materials. The backfill design will be developed during Intermediate (60%) RD following initial input from EPA on the dredge plan and will carefully consider how to balance achieving the ROD requirement to restore habitat areas to pre-dredge elevations, using imported backfill materials that may somewhat differ from the pre-dredge substrate. The Intermediate (60%) RD will design the backfill placement elevations and grades, which will be used to more precisely calculate the backfill design volumes.

Table 14-1
Summary of Preliminary (30%) RD Volumes

Description	Volume (cy)
Required Dredge Volume	84,900
Overdredge Allowance Volume	22,600
Contingency Re-dredging Volume	10,200
Total Payable Dredge Volume	117,700
Backfill Volume	56,400
RMC Volume	8,300
ENR Volume	1,000
Engineered Cap (Area 18) Volume	2,100
Total Placement Volume	67,800

Notes:
1. Volumes are rounded to the nearest hundred. See Appendix M for detailed dredging and material placement quantities.

ENR: enhanced natural recovery
RD: remedial design
RMC: residuals management cover

14.2 Opinion of Probable Cost

A Preliminary (30%) RD opinion of probable cost (Appendix M) was prepared based on the design information provided in the Preliminary (30%) Design Plans (Appendix D). The total project cost includes costs for direct construction tasks (i.e., all construction activities anticipated to be conducted by the contractor), indirect construction tasks (i.e., additional QA activities that are necessary to the project but are performed by parties other than the contractor), and additional construction oversight tasks (by the Implementing Entity and EPA).

Costs were developed using both parametric and bottom-up costing approaches. Parametric costing was based on review of historical cost estimates for 10 similar sediment remediation projects completed locally (in the Seattle area) and regionally (in the Pacific Northwest). In bottom-up costing, the large project was broken down into a number of smaller components, and costs were specifically derived for each of these smaller work components based on engineering cost guidance. By comparing bottom-up costs with parametric cost information (if projects reviewed contained similar quantities and/or conditions as the upper reach), along with engineering best professional judgment, "probable" unit costs were then derived. In addition, a three-point estimating approach was also applied to provide a costing range around the "probable" or "most likely" cost scenario (lower, probable, and upper cost scenarios).[22]

Costs developed for direct and indirect construction tasks and additional construction oversight tasks include the following components:

- Direct construction costs:
  a. Mobilization and demobilization
  b. Site preparation
  c. Surveys
  d. Structural work
  e. Dredging and excavation
  f. Transloading, upland transportation, and disposal
  g. Material placement
  h. Environmental controls
- Indirect construction costs:
  a. Construction management (inspection and oversight) and engineering support
  b. Confirmational sediment sampling
  c. Environmental monitoring during construction
  d. Site access agreements and temporary leases

[22] In three-point estimating, three separate cost scenarios for the costs associated with the project were generated. The first point represents an "optimistic" or "lower" cost scenario, the second point represents the "conservative" or "upper" cost scenario, and the third point represents the "probable" (or "most likely") cost scenario, which typically falls somewhere in the middle (see additional detailed information in Appendix M).

- Additional construction oversight costs:
  a. Implementing Entity oversight
  b. EPA oversight

General and specific RD costing assumptions are detailed in Appendix M and in the cost estimate workbook (Attachment M-1 to Appendix M). This Preliminary (30%) RD opinion of probable cost accounts for costing assumptions associated with the interim cap design for Area 18 and temporary relocation of structures for Area 13.

The total Preliminary (30%) RD opinion of probable (most likely) cost for LDW upper reach implementation at the Preliminary (30%) RD is $51.2 million (with a range of costs varying from a lower probable cost of $ 45.9 million to a higher probable cost of $61.4 million). Costs are presented in present-day U.S. dollars (i.e., 2022) and include sales tax (10.25%[23]) and contingency (30.0%, applied to the total direct and indirect construction costs, and to the additional construction oversight costs). Contingency percentage was selected to represent potential cost risks associated with the level of information available at Preliminary (30%) RD and engineering best professional judgment.

[23] Although the upper reach RAAs fall into both the Cities of Seattle and Tukwila jurisdictions, for the purposes of this opinion of probable cost, sales tax is included at 10.25% (to account for Washington State [6.5%] and the City of Seattle [3.75%] taxes), as a conservative assumption for Preliminary (30%) RD; sales tax for the City of Tukwila is 10.1%.

15 Construction Contracting Strategy

RD for the upper reach is being completed by LDWG under AOC4. Remedy construction will be implemented under a future Consent Decree or other enforcement mechanism, by the Implementing Entity (details to be determined). The Implementing Entity may be a group of public and private entities made up from the group of potentially responsible parties for the site identified by EPA.

The Implementing Entity will assign the responsibility of construction contracting to an experienced construction management firm or one of its members (Owner). The public or private nature of the organization will dictate the type of construction contract that will be used, the format of the drawings and specifications, and the specific legal arrangements between the selected remediation contractor and the Implementing Entity. For this Preliminary (30%) RD submittal, King County standards have been used for purposes of structuring the technical specifications outline.

15.1 Remediation Contractor Selection

The Implementing Entity will establish contractor selection criteria. The Implementing Entity will also develop its preferred contracting approach, including number of contracts, breakdown of work between contracts (if multiple contracts are used), insurance and bonding requirements, and contract administration processes. If the Implementing Entity contains one or more public entities, certain requirements will govern contractor selection in accordance with established public works contracting law.

15.2 Construction Quality Assurance Contract

It is expected that an experienced engineering consulting team will be contracted to perform construction QA activities independent of the construction contractor. The details for the field engineering and construction QA scope of work are described in Section 16.3.

15.3 Engineer of Record

Anchor QEA will serve as the Engineer of Record and will provide consultation and observations during construction to assist with implementation of the remedial action in conformance with the EPA-approved design documents, review of product approvals, request for information or clarifications, and acceptable design modifications as approved by EPA.

15.4 Number of Construction Contracts

The Implementing Entity may determine that it could be advantageous to engage in more than one agreement with different remediation contractors. Advantages of such an approach could include easier cost allocation or tracking, improved project sequencing, and greater depth of resources to complete remedial construction. Challenges associated with multiple contractors could include conflicts between overlapping contractor schedules or sequence, potentially blurry lines of responsibility, increased bottlenecks at key project pinch points (e.g., transloading and disposal), and greater construction contract administration overhead. On balance, the challenges of using a multiple-contractor approach are likely to outweigh the potential benefits and it is expected that the Implementing Entity will most likely not split the remedial construction of the upper reach into multiple construction contracts.

16 Contractor Quality Control and Construction Quality Assurance

A critical part of successful sediment remediation projects is to require that the contractor has a robust QC plan to manage their work in a manner that complies with all requirements identified in the plans and specifications and with all federal, state and local regulations. This section describes how QA/QC will be implemented during remedy construction.

16.1 Pre-Construction Activities

Following the construction contract award, the Implementing Entity will direct the selected contractor to develop a RAWP as a pre-construction submittal that will describe specific means and methods the contractor will use to implement the remediation construction activities. The design specifications will identify the components of the RAWP for which the contractor is responsible.

The contractor will also be required to develop an Emergency Response Plan documenting the procedures to be followed in the event of an accident or emergency during remedial construction. The Emergency Response Plan itself will be a component of the contractor's RAWP. Key components that will be required in the contractor's RAWP include the following:

- CQAP
- Project Work Plan, including (a) description of construction elements, including proposed means and methods; and (b) equipment and personnel list, including project organization chart and reporting responsibilities
- Initial Project Schedule
- Site Specific Construction Health and Safety Plan including an Emergency Response Plan
- Traffic Control Plan
- Environmental Pollution Control Plan including a Spill Prevention, Control, and Countermeasure Plan
- Transportation and Disposal Plan
- Surveying Plan including surveyor certifications (bathymetric and topographic)
- Material Placement Plan, including materials submittals per specifications (e.g., material testing results)
- Dredging and Excavation Plan, including proposed transload and disposal facility names, locations, and certification; and including water management plan
- Vessel Management Plan
- Demolition Plan
- Examples of progress reporting forms
- Change order forms and process

The RAWP will be reviewed and approved by the Implementing Entity and EPA.

16.2 Contractor Quality Control

Contractor QC refers to the procedures, actions, and documentation performed and produced by the contractor to demonstrate the contractor has met the project requirements as detailed in an approved RAWP and other EPA-approved pre-construction submittals, and with the design plans and specifications. Construction QC (e.g., daily progress surveys, equipment inspection, sampling and analysis to verify import materials quality) will be the responsibility of the construction contractor, in accordance with the specifications and the contractor's RAWP. The specifications developed in Intermediate (60%) RD will require the selected contractor to prepare a Contractor Quality Control Plan as part of the RAWP.

16.3 Construction Quality Assurance

Construction QA refers to the procedures and actions performed by the Implementing Entity to confirm that the contractor is complying with all project requirements, and to also provide QA related to the remedy performance. The CQAP that will be developed during Intermediate (60%) and Pre-Final (90%) RD will describe QA roles and responsibilities, QA activities, and the means and methods that the Implementing Entity and its consultant will use to provide QA during construction to oversee and track the contractor's work, monitor environmental compliance, and assess compliance with specifications.

For Preliminary (30%) RD, Appendix F identifies a summary list of key elements of the CQAP as required by AOC4. The CQAP will describe QA activities conducted during pre-construction, construction, and post-construction. Construction QA for sediment remediation projects typically involves three major categories of QA, including construction inspection and engineering support; environmental controls and monitoring; and remedy performance monitoring.

16.3.1 Construction Inspection and Engineering Support

The Implementing Entity will provide construction inspection (in-field activities) and engineering support (office support activities) to oversee the contractor's activities. The Implementing Entity may use a Resident Engineer, who is a full-time qualified individual, to lead the construction management team to oversee the contractor's work and help administer the construction contract. Construction management team responsibilities likely will include construction administration, on-site inspection, review of submittals, design interpretation and developing response actions, and communication and coordination with the selected contractor and EPA.

16.3.2 Environmental Controls and Monitoring

The Implementing Entity will provide environmental monitoring and reporting to EPA for all environmental ARARs compliance requirements, such as water quality monitoring. The CQAP will include development of environmental monitoring plans and response actions (i.e., how modifications to the construction procedures will be directed, as necessary, in response to monitoring data).

16.3.3 Remedy Performance Monitoring

The Implementing Entity will provide remedy performance monitoring, specifically to assess the post-dredge sediment surface quality to evaluate whether the post-dredge surface concentrations are below surface RALs (0-10 cm [0-4 inch]). The CQAP will describe the post-dredge confirmatory sampling and decision framework for contingency action(s) resulting from confirmatory sampling test results.

17 Work by Others

Work by others (bank or in-water construction activities such as permitted maintenance dredging, nearshore upland cleanup activities) within the limits of the upper reach may take place during the anticipated RD duration. Upper reach construction activities could modify existing conditions. Therefore, as described in the RDWP and with this BODR, any planned or completed construction activities within the upper reach starting in 2019 (representing the upper reach RD notice to proceed) through the anticipated RD completion in 2023 are currently being tracked.

Appendix O summarizes the status of in-water and bank construction activities occurring adjacent to the RAAs and anticipated changes in structures and in-water, riverbank, and upland areas. Construction activities have been documented by reviewing the *Lower Duwamish Waterway Source Control Status Report 2019* (Ecology 2021), accessing the *Water Quality Permitting and Reporting Information System (PARIS*), and through previous communications with water-dependent users (as part of the *Water User Survey and Assessment of In-Water Structures – Data Report;* Integral et al. 2018).

Should non-remediation-related construction take place between EPA approval of the Final (100%) RD and anticipated start of remedial construction, the Implementing Entity will review the new conditions and revise the drawings and specifications if necessary.

18 Phase III PDI Preliminary Data Gap Categories

During preparation of this Preliminary (30%) RD, three categories of data gaps were identified that will be addressed with a Phase III PDI for the upper reach. For planning purposes, the following major categories of data are expected to be collected during Phase III PDI:

- Additional horizontal chemistry sampling to refine RAA boundaries
- Additional vertical chemistry sampling in areas that are vertically unbounded
- Other engineering support data such as:
  - Survey data to fill small gaps in coverage identified during Preliminary (30%) RD
  - Additional information for select outfalls that are within action areas, including location confirmation, invert elevation and as-built data, if available

Details on the specific locations, samples, and methods will be presented in the Phase III PDI QAPP Addendum, which will be prepared separately and in coordination with EPA review and comments on the Preliminary (30%) RD. The Phase III PDI field work is expected to begin in late fall 2022.

19 References

AECOM, 2012. Final Feasibility Study, Lower Duwamish Waterway. Submitted to EPA October 2012.

Anchor QEA, 2019. Effects of Changes in Estimated Upstream Sediment Load on Lower Duwamish Waterway Sediment Transport Modeling, Memorandum to Kathy Godtfredsen, Windward Environmental, February 12, 2019.

Anchor QEA, 2021. Evaluation of Sedimentation Rates and Sediment Load Assumptions for Lower Duwamish Waterway Sediment Transport Model, Memorandum to Elly Hale, EPA, August 3, 2021.

Anchor QEA and Tetra Tech, 2016. Localized Remodeling of Contamination in OUs 4 and 5 of the Lower Fox River. Prepared for Boldt Oversight Team, Wisconsin Department of Natural Resources, and Kern Statistical. Document Control No. LFRR-15-0345A-R1.

Anchor QEA and Windward Environmental, 2019a. Remedial Design Work Plan for the Lower Duwamish Waterway Upper Reach. Final. Submitted to EPA December 16, 2019.

Anchor QEA and Windward Environmental, 2019b. Quality Assurance Project Plan: Pre-Design Surveys of the Lower Duwamish Waterway Upper Reach. Final. Submitted to EPA April 11, 2019.

Anchor QEA and Windward Environmental, 2020. Quality Assurance Project Plan for the Lower Duwamish Waterway Upper Reach: Pre-Design Investigation. Final. Submitted to EPA May 19, 2020.

Anchor QEA and Windward Environmental, 2021a. Quality Assurance Project Plan Addendum for the Lower Duwamish Waterway Upper Reach: Pre-Design Investigation Phase II. Final. Submitted to EPA June 25, 2021.

Anchor QEA and Windward Environmental, 2021b. Quality Assurance Project Plan Addendum: Pre-Design Surveys of the Lower Duwamish Waterway Upper Reach. Final. Submitted to EPA June 25, 2021.

Anchor QEA and Windward Environmental, 2022a. Pre-Design Investigation Data Evaluation Report. Final. Submitted to EPA July 15, 2022.

Anchor QEA and Windward, 2022b. Cross-Validation Technical Memorandum. Draft. Submitted to EPA July 28, 2022.

Battelle (Battelle Marine Sciences Laboratory), Pentec Environmental, Striplin Environmental Associates, Shapiro Associates, Inc., and King County Department of Natural Resources, 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).

Blomberg G., Simenstad C., Hickey P., 1988. Changes in Duwamish River estuary habitat over the past 125 years. In: Proceedings of the First Annual Meeting on Puget Sound Research, Seattle.

BOEM and NOAA (Bureau of Ocean Energy Management and National Oceanic and Atmospheric Administration), 2021. MarineCadastre.gov. Nationwide Automatic Identification System 2020. Retrieved June 1, 2021 from marinecadastre.gov/data.

CIG/UW (Climate Impacts Group-University of Washington), 2017. Projected Changes in Climate and Hydrology for Puget Sound and Adaptation Strategies. Lower Duwamish Waterway Superfund Site: Climate Change Adaptation Workshop (Seattle, Washington); March 2017.

Desrosiers, R. and C. Patmont, 2009. Environmental Dredging Residuals – Case Study Summaries and Analyses. Presented at 5th International Conference on Remediation of Contaminated Sediments. February 4, 2009.

Ecology (Washington State Department of Ecology), 2021. Lower Duwamish Waterway Source Control Status Report 2019. Washington State Department of Ecology. Publication No. 21-09-174. November 2021.

Ecology, 2022. Duwamish Waterway Park [online]. Washington State Department of Ecology. Available from: https://apps.ecology.wa.gov/cleanupsearch/site/15139.

EPA (U.S. Environmental Protection Agency), 1998. Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual. February 1998.

EPA, 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012, OSWER 9355.0-85. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. December 2005.

EPA, 2009. Clean and Green Policy. Prepared by Office of Environmental Cleanup, Office of Air, Waste, and Toxics, and Office of Compliance and Enforcement. August 13, 2009.

EPA, 2010. Superfund Green Remediation Strategy. September 2010.

EPA, 2012a. Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites. December 2012.

EPA, 2012b. Institutional Controls: A Guide to Preparing Institutional Control Implementation and Assurance Plans at Contaminated Sites. December 2012.

EPA, 2012c. Methodology for Understanding and Reducing a Project's Environmental Footprint. Prepared by Office of Solid Waste and Emergency Response and Office of Superfund Remediation and Technology Innovation. EPA 542-R-12-002. February 2012.

EPA, 2014. Record of Decision. Lower Duwamish Waterway Superfund Site.

EPA, 2015. Climate Change Adaptation Technical Fact Sheet: Contaminated Sediment Remedies. Available at: [https://www.epa.gov/sites/production/files/2018-08/documents/contaminated_sediments.pdf. April 2015](https://www.epa.gov/sites/production/files/2018-08/documents/contaminated_sediments.pdf).

EPA, 2017. Guidance for Management of Superfund Remedies in Post Construction. February 2017.

EPA, 2021. Explanation of Significant Differences. Lower Duwamish Waterway Superfund Site. September 2021.

Everest, F.H. and D.W. Chapman, 1972. Habitat Selection and Spatial Interaction by Juvenile Chinook Salmon and Steelhead Trout in Two Idaho Streams. Journal of the Fisheries Research Board of Canada 29:91-100.

FEMA (Federal Emergency Management Agency), 2013. Procedures for "No-Rise" Certification for Proposed Developments in the Regulatory Floodway. October 2013.

Fresh, K.L., 2006. Juvenile Pacific Salmon in Puget Sound. Prepared in Support of the Puget Sound Nearshore Partnership. NOAA Fisheries Service, Northwest Fisheries Science Center. Technical Report 2006-06.

Hayes, D.F. C.H. Je, 2000. DREDGE Model User's Guide. University of Utah, Department of Civil and Environmental Engineering. July 2000.

Hillman, T.W., J.S. Griffith, and W.S. Platts, 1987. Summer and Winter Habitat Selection by Juvenile Chinook Salmon in a Highly Sedimented Idaho Stream. Transactions of the American Fisheries Society 116:185-195.

Integral, Moffatt & Nichol, and Windward Environmental, 2018. Waterway User Survey and Assessment of In-Water Structures – Data Report. Prepared for U.S. Environmental Protection Agency, Region 10. July 2, 2018.

Ippen, A., 1966. Estuary and Coastline Hydrodynamics. New York: McGraw-Hill Book Company.

Johnson, S.W., J.F. Thedinga, and K.V. Koski, 1992. Life History of Juvenile Ocean-type Chinook Salmon (*Oncorhynchus tshawytscha*) in the Situk River, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 49:2621-2629.

KCDNR (King County Department of Natural Resources and Parks), Department of Executive Services, Department of Local Services, Department of Public Health-Seattle & King County, 2021. King County Lower Duwamish Source Control Annual Report Year 2020. Prepared for: Washington State Department of Ecology. October 2021.

Kern J., Wolfe J., Barabas N., 2008. Evaluation of Increased Sampling Density for Refinement of 30% Dredge Prism Design in Upper OU3 in Attachment C to Appendix D. Lower Fox River Remedial Design 100 Percent Design Report. Construction Quality Assurance Project Plan for 2009 Remedial Actions. For Submittal to Wisconsin Department of Natural Resources and U.S. Environmental Protection Agency. Kern Statistical Service and LimnoTech.

King County Department of Transportation, 2010. South Park Bridge #3179 Replacement Contract Drawings.

Leidos, 2014. Lower Duwamish Waterway Outfall Inventory Update, January 2012 – February 2014. Prepared for Washington State Department of Ecology. Leidos, Bothell, WA. SC_00035548.

Leidos, 2020. Lower Duwamish Waterway Outfall Inventory Update, August 2020. Prepared for Washington State Department of Ecology. Leidos, Bothell, WA.

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover, 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle.

McKeon, M.A., Horner-Devine, A.R. and Giddings, S.N. Seasonal Changes in Structure and Dynamics in an Urbanized Salt Wedge Estuary. Estuaries and Coasts 44, 589–607 (2021). https://doi.org/10.1007/s12237-020-00788-z

Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., and Grossman, E., 2018. Projected Sea Level Rise for Washington State – A 2018 Assessment. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, University of Oregon, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project.

NMFS (National Marine Fisheries Services), 2005. Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon. NOAA Technical Memorandum NMFS-NWFSC-68. August 2005.

NOAA (National Oceanic and Atmospheric Administration), 2017. Navigation Chart 18450. Seattle Harbor Elliott Bay and Duwamish Waterway.

NOAA, 2000. Appendix A: Habitat Equivalency Analysis: An Overview. NOAA Damage Assessment and Restoration Program, Department of Commerce. Revised October 4, 2000. Appendix to the 2002 Hylebos Waterway Natural Resource Damage Settlement Proposal Report: Habitat Restoration-Based Approach for Resolving Natural Resource Damage Claims Relating to the Hylebos Waterway of the Commencement Bay Nearshore/Tideflats Superfund Site Combined with a Proposal for Allocating Liability for Settlement Purposes. 2000.

ODFW (Oregon Department of Fish and Wildlife), 2005. Biology, Behavior, and Resources of Resident and Anadromous Fish in the Lower Willamette River, Final Report of Research, 2000-2004. Edited by Thomas Friesen, ODFW. Prepared for City of Portland Bureau of Environmental Services, Endangered Species Act Program.

Palermo, M., S. Maynord, J. Miller, and D. Reible, 1998. Guidance for In-Situ Subaqueous Capping of Contaminated Sediments. EPA 905-B96-004, Great Lakes National Program Office, Chicago, Illinois.

PSLC (Puget Sound LiDAR Consortium), 2016. LiDAR data. https://pugetsoundlidar.ess.washington.edu/

Public Health Seattle and King County, 2019. US EPA's Institutional Control Implementation and Assurance Plan (ICIAP) for Seafood Consumption at the Lower Duwamish Waterway (LDW) Superfund Site. Final. August 2019.

QEA (Quantitative Environmental Analysis, LLC), 2007. Hudson River PCBs Site Phase 2 Dredge Area Delineation Report. Prepared for General Electric Company. Quantitative Environmental Analysis, LLC, Glen Falls, NY.

QEA, 2008. Sediment Transport Model Report – Final. Prepared for EPA, Region 10, Seattle, WA, and Washington State Department of Ecology, Northwest Regional Office, Bellevue, WA. October 2008.

Reible, D., 2017. CapSim 3.5 Quick-Start Manual. Available at: https://www.depts.ttu.edu/ceweb/groups/reiblesgroup/downloads/CapSim%203.6%20Quick%20Start%20Manual.docx.

Ruggerone, G.T., T.S. Nelson, J. Hall, and E. Jeanes, 2005. 2005 Juvenile Chinook Duwamish River Studies—Habitat Utilization, Migration Timing, Growth, and Diet of Juvenile Chinook Salmon in the Duwamish River and Estuary. Prepared for WRIA 9 Technical Committee and Steering Committee. Prepared by Natural Resources Consultants, King County, City of Seattle, and R2 Resource Consultants. Funded by King Conservation District and Salmon Recovery Funding Board. May 2006.

Seaport Planning Group, 2009. Lower Duwamish River Habitat Restoration Plan: An Inventory of Port of Seattle Properties. Final Draft. January 2009.

Thornburg T., Wolfe J., Barabas N., 2005. Comparative Evaluation of Geostatistical Methods for Delineating PCB Remediation Areas and Volumes, Lower Fox River. Society of Environmental Toxicologists and Chemists, 26th Annual North American Meeting, Baltimore, MD, November 13-17, 2005.

Tiffan, K.F., L.O. Clark, R.D. Garland, and D.W. Rondorf, 2006. Variables Influencing the Presence of Subyearling Fall Chinook Salmon in Shoreline Habitats of the Hanford Reach, Columbia River. North American Journal of Fisheries Management 26:351-360, 2006.

USACE (U.S. Army Corps of Engineers), 1992. *Automated Coastal Engineering System (ACES)*. Technical Reference by D.E. Leenknecht, A. Szuwalski, and A.R. Sherlock, Coastal Engineering Center, Department of the Army, Waterways Experiment Station, Vicksburg, Mississippi. September 1992.

USACE, 2003. Slope Stability. Engineering Manual EM 1110-2-1902.

USACE, 2004. General Design and Construction Considerations for Earth and Rock-Fill Dams. Engineer Manual 1110-2-2300. Department of the Army, U.S. Army Corps of Engineers, Washington, D.C. July 10, 2004.

USACE, 2014. Howard Hanson Dam, Green River, Washington, Climate Change Impacts and Adaptation Study. U.S. Army Corps of Engineers, Seattle District, April 2014.

USACE, 2008a. Technical Guidelines for Environmental Dredging of Contaminated Sediments. Technical Report ERDC/EL TR-08-29. Vicksburg, MS: U.S. Army Engineer Research and Development Center. September 2008.

USACE, 2008b. The 4 Rs of Environmental Dredging: Resuspension, Release, Residuals, and Risk. Prepared by Todd S. Bridges, Stephen Ells, Donald Hayes, David Mount, Stephen C. Nadeau, Michael R. Palermo, Clay Patmont, and Paul Schroeder, ERDC/EL TR-08-4. January 2008.

USGS (U.S. Geological Survey), 2018. Suspended-Sediment Transport from the Green-Duwamish River to the Lower Duwamish Waterway, Seattle, Washington, 2013-17. C.A. Senter, K.E. Conn, R.W. Black, N. Peterson, A. Vanderpool-Kimura, and J.R. Foreman. Open-File Report 2018-1029.

Wang, T.S., Larm, K., and D. Hotchkiss, 2002. Evaluation of Closed Buckets for Remedial Dredging and Case Histories. Proceedings – Third Specialty Conference on Dredging and Dredged Material Disposal, ASCE Dredging 2002. Orlando, FL. May.

Weggel, J.R., and R.M. Sorensen, 1986. *A Ship Wave Prediction for Port and Channel Design*. Proceedings of the Ports '86 Conference: Oakland, California, May 19 to 21, 1986. Paul H. Sorensen, ed. New York: American Society of Civil Engineers, 797–814.

Windward (Windward Environmental), 2004. Lower Duwamish Waterway Remedial Investigation. Intertidal Clam Survey Data Report. Prepared for Lower Duwamish Waterway Group.

Windward, 2010. Lower Duwamish Waterway Remedial Investigation. Remedial Investigation Report. Final. Submitted to EPA July 2010.

Wolfe J., Kern J., 2008. Ground Rules for Evaluating Extent of Vertical and Horizontal Remedial Coverage. Attachment A-8 to Appendix A. Dredging and Materials Handling Design Support Documentation in the Lower Fox River Remedial Design 100 Percent Design Report for 2009 Remedial Actions. For Submittal to Wisconsin Department of Natural Resources and US Environmental Protection Agency. Kern Statistical Services and LimnoTech.

Wood Environmental & Infrastructure Solutions, Inc., Ramboll, Floyd|Snider, Geosyntec Consultants, and Integral Consulting, 2021. Year 3 Monitoring Report, Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway. Final. Approved by EPA October 2021.