Lower Duwamish Waterway Group

City of Seattle / King County / The Boeing Company

Phase I Pre-Design Investigation Data Evaluation Report for the Lower Duwamish Waterway – Middle Reach Draft

For submittal to

U.S. Environmental Protection Agency
Seattle, WA

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ABBREVIATIONS

AST	area-specific technology
BBP	butyl benzyl phthalate
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
DER	Data Evaluation Report
DQP	data quality objective
ENR	enhanced natural recovery
EPA	U.S. Environmental Protection Agency
ESD	explanation of significant differences
FNC	Federal Navigation Channel
FS	feasibility study
GC	gas chromatography
HCB	hexachlorobenzene
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HRGC	high-resolution gas chromatography
HRMS	high-resolution mass spectrometry
ICP	inductively coupled plasma
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
MHHW	mean higher high water
MLLW	mean lower low water
MNR	monitored natural recovery
MS	mass spectrometry
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PD&C	partial dredge and cap
PDI	Pre-Design Investigation
PDIWP	pre-design investigation work plan
QAPP	quality assurance project plan
QC	quality control
RAA	remedial action area
RAL	remedial action level
RAO	remedial action objective
RD	remedial design
RDWP	remedial design work plan

RI	remedial investigation
RM	river mile
ROD	Record of Decision
SCO	sediment cleanup objective
SDG	sample delivery group
SIM	selected ion monitoring
SVOC	semivolatile organic compound
TOC	total organic carbon

1 Introduction

This document, the Phase I Data Evaluation Report (DER), supports remedial design (RD) for the middle reach (river mile [RM] 1.6 to RM 3.0) of the Lower Duwamish Waterway (LDW) Superfund site in King County, Washington. Per the fifth amendment to the Administrative Order on Consent, this Phase I DER presents the results of the Phase I Pre-Design Investigation (PDI), re-assesses recovery categories, defines areas with exceedances of the remedial action levels (RALs),[1] lists preliminary technology assignment options for these areas, and identifies general data gaps for the Phase II PDI. Data collection to address these data gaps is outlined in an Addendum to the PDI Quality Assurance Project Plan (QAPP) for Phase II (Anchor QEA and Windward 2023b), herein referred to as the Phase II QAPP Addendum. This Phase I DER has been prepared on behalf of the City of Seattle, King County, and The Boeing Company, collectively referred to as the Lower Duwamish Waterway Group (LDWG).

1.1 Phase I Data Evaluation Report Objectives

Per the remedial design work plan (RDWP) (Anchor QEA and Windward 2022b), design sampling is being done in phases (Figure 1-1). Phase I is focusing on defining the horizontal extent of RAL exceedance areas, and on listing technology assignment options in order to identify Phase II PDI data gaps. Phase II will involve the collection of data within the middle reach[2] to further delineate the areas with RAL exceedances in surface sediment (0 to 10 cm), subsurface sediment (0 to 45 cm in the intertidal and 0 to 60 cm in the subtidal), and Federal Navigation Channel (FNC) shoaling areas. Phase II will also assess the overall depth of contamination in dredge or partial dredge and cap (PD&C) areas, and will involve collecting characterization data, as needed, within areas with RAL exceedances, including bank data, geotechnical data, and area-specific engineering data for RD. Phase III will be conducted if data gaps remain after Phase II is complete.

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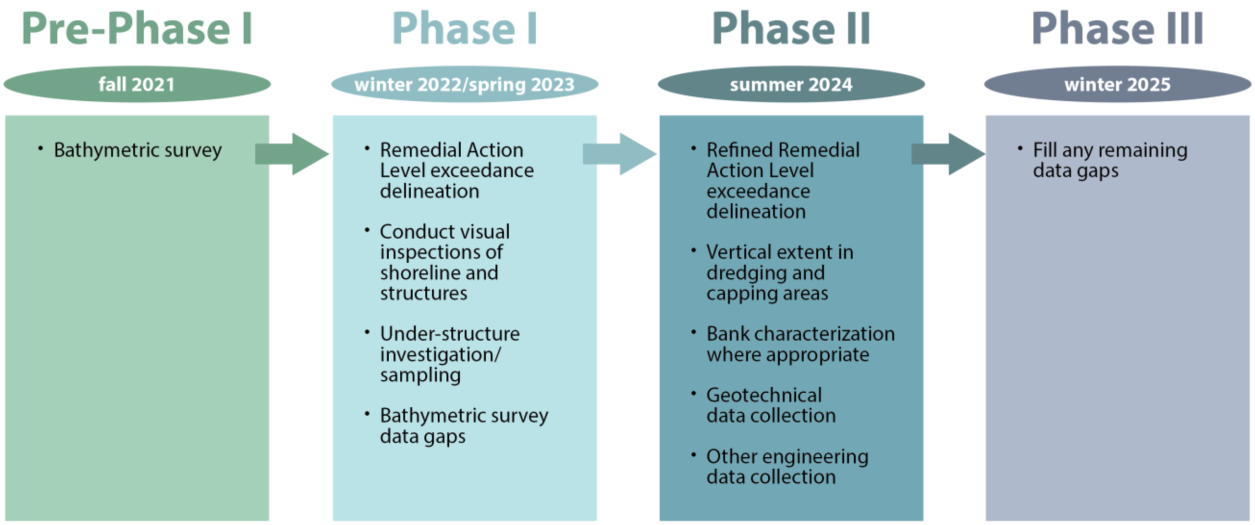
[1] RALs are defined in Table 28, titled *Remedial Action Levels, ENR Upper Limits, and Areas and Depths of Application*, of the US Environmental Protection Agency's (EPA's) November 2014 Record of Decision (ROD) (EPA 2014). As stated in the ROD, a RAL is a contaminant concentration above which remedial action is required. Carcinogenic polycyclic aromatic hydrocarbon (cPAH) RALs are defined in the explanation of significant differences (ESD) (EPA 2021).

[2] In the Pre-Design Investigation work plan (PDIWP) (Windward and Anchor QEA 2023), the middle reach included only the outer portion of the inlet at RM 2.2W. Discussions are ongoing regarding which regulatory program (the Model Toxics Control Act or Superfund) will address the remediation of the inlet, and whether it will be split between programs.

DRAFT

Figure 1-1
Design Sampling Phases



Per the RDWP and PDIWP (Anchor QEA and Windward 2022b; Windward and Anchor QEA 2023), this Phase I DER meets the following objectives in the overall RD process.

- Summarize the results of the Phase I PDI, including results from the sediment chemistry analyses (Tiers 1 and 2), bank visual inspection, and structures visual inspection.
- Discuss any revisions to recovery categories based on bathymetry data collected in 2023, as well as Phase I chemistry data at re-occupied locations.
- Define preliminary areas with RAL exceedances.
- Identify preliminary technology assignment options for each area with RAL exceedances consistently with the decision trees in the ROD (Figure 19 and updated Figure 20 of the ROD).
- Identify general Phase II data gaps, which are addressed in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b).
- Provide a Phase I PDI bathymetric data gaps survey data report with methods, deviations, and data.

The preliminary areas with RAL exceedances presented in this Phase I DER will be updated with Phase II data and refined in the Phase II DER. Based on the locations of these areas and other engineering considerations, remedial action areas (RAAs) will be defined at 30% RD and then refined and grouped into sediment management areas at 60% RD, as discussed in the RDWP (Table 1-1) (Anchor QEA and Windward 2022b).

Table 1-1
Areas to be Defined During the RD Process

Area	Definition	Where Defined
RAL exceedance area	Area where RAL is exceeded by at least one contaminant based on comparison of interpolated concentrations to RALs in ROD Table 28 and the cPAH ESD	Phase I DER; areas will be refined in the Phase II DER using Phase II data
RAA	Area developed by considering how the selected remedial technologies are constructed and overlaying engineering considerations; RAA boundaries are set at or beyond the final interpolated boundaries of the RAL exceedance areas	30% RD
Sediment management area	Area organized by grouping RAAs by remedial technology, site physical conditions, or operational restrictions	60% RD

Notes:
cPAH: carcinogenic polycyclic aromatic hydrocarbon
DER: data evaluation report
ESD: explanation of significant differences
RAA: remedial action area
RAL: remedial action level
RD: remedial design
ROD: Record of Decision

The areas with RAL exceedances delineated in this document will likely be different than the RAAs in 30% RD, because the RAAs:

- Will be based on a larger design dataset[3] that will include Phase II PDI data
- Will include engineering considerations, such as geotechnical, slope and structural stability; sediment stability; and constructability

1.2 Data Quality Objectives

The PDI QAPP (Windward and Anchor QEA 2022) presented data quality objectives (DQOs) for Phase I (Table 1-2). DQOs 1 through 7 were met by Phase I sediment sampling at 303 locations from December 2022 through May 2023. Chemical analysis was conducted and the results, combined with existing sediment design data, provided a preliminary horizontal footprint of RAL exceedances. DQO 8 was addressed through visual surveys conducted during a series of daytime low tides in June 2023. Phase II DQOs, as discussed in Section 4 of this document, will be met through Phase II sampling. Details of the Phase II sampling are outlined in the Phase II QAPP Addendum.

[3] The design dataset is defined in Section 3.1.1 of the PDIWP (Windward and Anchor QEA 2023) and is summarized in Section 3.1 of this document.

Table 1-2
DQOs for Phases I and II of the PDI in the Middle Reach

Phase I	Phase II
DQO1 – Delineate 0–10-cm RAL exceedances in Recovery Category 2/3 DQO2 – Delineate 0–10-cm RAL exceedances in Recovery Category 1 DQO3 – Delineate 0–45-cm intertidal RAL exceedances in Recovery Category 2/3 DQO4 – Delineate 0–45-cm intertidal RAL exceedances in Recovery Category 1 DQO5 – Delineate 0–60-cm PCB RAL exceedances in potential vessel scour areas in Recovery Category 2/3 DQO6 – Delineate 0–60-cm RAL exceedances in Recovery Category 1 DQO7 – Delineate RAL exceedances in shoaling areas DQO8 – Conduct a visual inspection of the structures and banks in the middle reach to identify features relevant to design, such as the presence/absence of bank armoring, and to plan how to access banks and areas under structures for sampling purposes DQO9 – Sample areas under structures, if feasible, safe, and appropriate, to delineate RAL exceedances	DQO10 – Further delineate RAL exceedances, as needed for unbounded areas[1] DQO11 – Assess chemical and physical characteristics of sediment in banks, as needed, depending on remedial technology selected and whether or not the bank is erosional DQO12 – Delineate vertical elevation of RAL exceedances in dredge (and dredge/cap) areas and collect vertical information in cap areas where deeper contamination under caps may be located[2] DQO13 – Collect geotechnical data as needed depending on technology proposed and/or physical characteristics of remedial action areas DQO14 – Collect other engineering applicable data as needed (e.g., structures inspection, utility location verification, thickness of sediment on top of riprap layers)

Notes:
The topographic survey in bank areas within RAL exceedance areas will be conducted in Phase II and will be described in a Survey QAPP Addendum, including survey-specific DQOs.
1. Benthic toxicity testing may be used to override chemical data in RAL delineation (DQO 10), per the ROD (EPA 2014).
2. Vertical delineation includes an assessment of whether an additional 1 feet of dredging in PD&C areas would be sufficient to achieve complete removal, as shown in ROD Figure 20.
DQO: data quality objective
PCB: polychlorinated biphenyl
PDI: Pre-Design Investigation
QAPP: quality assurance project plan
PD&C: partial dredge and cap
RAL: remedial action level
ROD: Record of Decision

1.3 Report Organization

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

- Section 2. Phase I PDI Summary
- Section 3. Data Evaluation
- Section 4. Phase II Data Gaps
- Section 5. Next Steps
- Section 6. References

The following appendices are attached to this document.

- Appendix A. Bank Visual Inspection Observations and Photographs
- Appendix B. Structures Visual Inspection Forms
- Appendix C. PDI Bathymetric Survey Data Report
- Appendix D. Data Management Rules
- Appendix E. Recommended Recovery Category Modifications
- Appendix F. Interpolation Methods for Delineating Areas with RAL Exceedances
- Appendix G. Preliminary Technology Assignment Options for Areas with RAL Exceedances
- Appendix H. cPAH RAL Exceedance Areas Relative to 2014 ROD RALs
- Appendix I. Middle Reach Design Dataset Including PDI Phase I Data

The middle reach Phase I data package posted on https://ldwg.org contains the data file, maps with location numbers, locations coordinates (targets vs. actuals) and mudlines (RTK vs. Bathymetry), chain of custody forms, photographs, field forms, and laboratory and validation reports.

2 Pre-Design Investigation Summary

This section presents the results of the Phase I PDI, including sediment sampling, bank visual inspection, structures visual inspection, bathymetry surveying, and inadvertent discovery plan implementation.

2.1 Sediment Sampling

2.1.1 Field Sampling Overview

From December 2022 to May 2023, Phase I sediment samples were collected from 303 locations throughout the middle reach of the LDW (RM 1.6 to RM 3.0) (Map 2-1). Surface sediment grab samples were collected at 262 locations, and subsurface sediment and shoaling cores were collected at 237 locations in the FNC (Map 2-2). Field logbooks, field collection and processing forms, chain of custody forms, and photographs of surface sediment grab and subsurface sediment core samples were provided as part of the Phase I data package posted on https://ldwg.org.

2.1.1.1 Field Methods

Surface grab samples and subsurface sediment cores were collected and processed following the standard operating procedures described in the PDI QAPP for the Middle Reach (Windward and Anchor QEA 2022). Generally, sediment samples were collected from the target depths using a pneumatic grab sampler (for surface sediment) or a vibracorer (for subsurface and shoaling cores). A subset of samples were collected manually at some intertidal locations during a daytime low tide. Under-structure samples were collected either manually by divers or by hand (on foot) during a daytime low tide at some intertidal locations.

2.1.1.2 Field Deviations

Deviations from the PDI QAPP involved modifications to sediment core acceptance criteria, sampleability at the target location, and sample processing. EPA was notified of all deviations when samples were collected. The field deviations did not affect the data quality for use in the PDI.

Deviations related to core acceptance criteria were as follows:

- Location 1236 – The subsurface core at this location achieved the full target penetration but had a percent recovery that was less than the target of 75%. The core from the best of the three attempts at this location (recovery of 72%) was retained for analysis.
- Locations 1803 and 1804 – As a result of the silty nature of the sediment at these locations under the structure at Terminal 115, some material was lost from the bottom of the

subsurface cores upon core extraction from the sediment. In both cases, recovery was acceptable (≥75%).

- Location 1803: The drive depth at this location was 2.5 feet, with a recovery of 88%. During extraction of the core from the sediment, about 6 inches of material was lost from the bottom of the core. After recovery correction, the remaining sediment was determined to represent the top 56.5 cm of sediment (94% of the targeted 60 cm). This core was accepted for processing.
- Location 1804: The first attempt at this location was rejected (about 8 inches of material was lost). The drive depth of the second attempt was 2.0 feet, with a recovery of 93%. During extraction of the core from the sediment, about 4 inches of material was lost from the bottom of the core. After recovery correction, the remaining sediment was determined to represent the top 48.4 cm of sediment (81% of the targeted 60 cm). This core was accepted for processing.

Deviations related to sample placement and sampleability were as follows:

- Location 1035 – Sample collection at this location was attempted by hand during the daytime low tide sampling on April 11, 2023. No exposed sediment was observed within 30 feet of the location, and the bathymetry in this area suggested that the riprap continued throughout this entire grid cell, including the subtidal area. Per discussion with EPA, the target for this location was shifted to the subtidal area offshore of the nearby outfall. Probing was conducted before attempting sample collection to determine the extent of the riprap. Both a surface sediment sample (0 to 10 cm) and subsurface sediment sample (0 to 60 cm) were successfully collected at the edge of the riprap on May 8, 2023. A core was successfully collected on the fourth attempt, each subsequent attempt having been performed farther from the shoreline and riprap.
- Location 1087 – Sample was collected 30.2 feet from the target location. Target location was above mean higher high water (MHHW) in an area under the First Ave S bridge that was not sampleable. The sample was collected from a nearby representative intertidal location.
- Locations 1126 and 1134 – Surface sediment samples were successfully collected at these intertidal locations, but subsurface sediment samples could not be collected. Sample collection was attempted using a vibracorer (two intertidal attempts and three subtidal attempts) and by hand at low tide. Penetration was insufficient on all attempts due to the presence of riprap in this area.

Deviations related to sample processing were as follows:

- Locations 1812 and 1813 – Cores were collected by divers on April 3, 2023, under the Seattle Iron and Metals wharf. After a quality control (QC) review of field-calculated mudline elevations at both under-structure locations, it was discovered that the core samples had been erroneously homogenized as 0- to 60-cm subtidal samples rather than 0- to 45-cm intertidal samples. After consulting EPA, the 0- to 60-cm samples were analyzed and compared to the 0- to 45-cm RALs for the Recovery Category 2/3 area, rather than risk diver safety to recollect these cores.

2.1.1.3 Count of Samples Collected and Analyzed

Counts of locations and intervals sampled during the Phase I PDI sampling effort are summarized in Table 2-1. Field duplicates are not included in the sample counts. The sediment depth intervals collected at each location, as specified in the QAPP, are based on the bathymetry of the sample location (intertidal, subtidal, or shoaling area) and the recovery category, consistent with ROD Table 28 (Windward and Anchor QEA 2022). Targeted depth intervals in the FNC shoaling areas are shown in Figure 2-1; Map 2-3 shows the intervals sampled at each shoaling location during the Phase I PDI effort.

Table 2-1
Summary of Middle Reach Locations Sampled during the Phase I PDI

Sample Type	Depth Interval	Count of Locations Sampled[1]
Surface Sediment Locations		
Intertidal	0–10 cm	64
Subtidal	0–10 cm	198
Subtotal		***262***
Subsurface Sediment Locations		
Intertidal	0–45 cm	69
Subtidal[2]	0–60 cm	129
Shoaling cores	Variable	39
Subtotal		***237***
Total Locations Sampled[3]		**303**

Notes:
1. Sample counts include all sediment samples collected during Phase I, including those collected under structures.
2. The number of 0–60-cm locations does not include shoal core locations.
3. The total count of locations is less than the sum of the counts by location type because many locations have results for multiple intervals.
PDI: Pre-Design Investigation

For many locations, multiple samples were collected, and thus the location counts and sample counts do not match. For example, in Phase I, in the intertidal areas, a surface sediment (0- to 10-cm) sample and/or a subsurface intertidal sediment (0- to 45-cm) sample were generally collected at each location; in the subtidal areas, a surface sediment (0- to 10-cm) sample and/or a subsurface sediment (0- to 60-cm) sample were generally collected at each location. In the shoaling areas within the FNC, cores were collected to characterize the shoal material above the authorized navigation depth, the 60-cm interval below the authorized depth (i.e., the allowable overdredge interval), and Z samples below the overdredge interval (Map 2-3).

2.1.2 Laboratory Testing Overview

2.1.2.1 Chemical Analysis Methods

The methods and procedures used to chemically analyze the sediment samples are detailed in the QAPP (Windward and Anchor QEA 2022). This section summarizes those methods and discusses laboratory deviations from the QAPP. Laboratory and validation reports and the full chemistry results for Phase I are provided in the data packages posted on https://ldwg.org.

Analytical Resources, Inc. performed the sediment chemical analyses according to the methods presented in Table 2-2. Table 2-3 provides counts of Phase I samples analyzed for at least one analyte, and Table 2-4 provides a summary of analyses per analyte.

Table 2-2
Analytical Methods for Sediment Analyses

Analyte	Method	Reference	Extraction Solvent
PCB Aroclors	GC/electron capture detection	EPA 3546 Mod EPA 8082A	Hexane/acetone
cPAHs[1,2]	GC/MS-SIM	EPA 3546/ EPA 8270E-SIM	Dichloromethane/acetone
PAHs[4]/SVOCs[3]	GC/MS	EPA 3546/ EPA 8270E/EPA 8270E-SIM	Dichloromethane/acetone
HCB	GC/electron capture detection	EPA 3546/EPA 8081B	Hexane/acetone
Dioxins/furans	HRGC/HRMS	EPA 1613b	Toluene
Metals	ICP-MS	EPA 3050B EPA 6020B UCT-KED	NA
Mercury	cold vapor-atomic fluorescence spectroscopy	EPA 7471B	NA
TOC	high-temperature combustion	EPA 9060A	NA
Percent solids	drying oven	SM 2540G	NA

Notes:
1. Per the ROD (EPA 2014), cPAHs consist of a subset of seven PAHs that EPA has classified as probable human carcinogens: benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene.
2. cPAHs were analyzed by 8270E-SIM in samples that required only cPAH analysis (i.e., 0–45-cm samples in Recovery Category 2/3) and not the full SVOC list.
3. In the analysis of the full SVOC list, 2,4-dimethylphenol, benzoic acid, benzyl alcohol, n-Nitrosodiphenylamine, pentachlorophenol, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, and 1,4-dichlorobenzene were analyzed by 8270-SIM.
cPAH: carcinogenic polycyclic aromatic hydrocarbon
EPA: U.S. Environmental Protection Agency
GC: gas chromatography
HCB: hexachlorobenzene

HRGC: high-resolution gas chromatography
HRMS: high-resolution mass spectrometry
ICP: inductively coupled plasma
MS: mass spectrometry
NA: not applicable
PAH: polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
ROD: Record of Decision
SIM: selected ion monitoring
SVOC: semivolatile organic compound
TOC: total organic carbon

Table 2-3
Summary of Upper Reach Samples Collected and Analyzed for at Least One Analyte During the Phase I PDI

Phase	Category	No. of Samples[1]				
		RAL Interval Samples				Samples Below RAL Interval (Z-Layer)
		Surface Sediment (0–10 cm)	Subsurface Sediment		Shoal Intervals	
			Intertidal (0–45 cm)	Subtidal (0–60 cm)[2]		
Phase I	Total collected	262	69	129	87	39
	Total analyzed	259	69	129	62	8
	Total archived	3	0	0	25	31

Notes:
1. Sample counts include all samples submitted for analysis through May 2023. Field duplicates are not included in sample counts.
2. The number of 0–60-cm locations does not include shoal core locations.
PDI: Pre-Design Investigation
RAL: remedial action level

Table 2-4
Total Number of Chemical Analyses in Phase I samples

Sediment Type (depth interval)	Total Samples Analyzed	No. of Samples Analyzed[1,2]								
		Human Health Risk Drivers				Other Benthic Risk Drivers[3]				
		PCB Aroclors	Dioxins/ Furans	Arsenic	cPAHs	Other Metals	PAHs	Phthalates	Other SVOCs	TOC
Surface (0–10 cm)	259	258	52	242	241	243 (1 Hg only)	241	238	239	259
Subsurface intertidal (0–45 cm)	69	69	23	69	69	5	5	5	5	69
Subsurface subtidal (0–60 cm)	129	129	9	58	58	58	58	58	58	129
Shoal intervals (depth varies)[4]	62	62	15	62	62	62	62	62	62	62

Notes:
1. Sample counts include PDI samples submitted for analysis through May 2023 and do not include field duplicates.
2. This table presents only the PDI dataset; the full design dataset is summarized in Section 3.
3. Other benthic risk drivers include RAO 3 COCs; PCBs and arsenic are counted separately. Other metals (cadmium, chromium, copper, lead, mercury, silver, and zinc), phthalates (BEHP, BBP, and dimethyl phthalate), PAHs (2-methylnaphthalene, acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, dibenzofuran, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, pyrene, total benzofluoranthenes, total HPAHs, total LPAHs), and SVOCs (1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, 2,4-dimethylphenol, 4-methylphenol, benzoic acid, HCB, n-nitrosodiphenylamine, pentachlorophenol, and phenol) are counted if at least one of the analytes in the group was analyzed.
4. Shoal interval samples consisted of shoaled material from the FNC and sediment from the overdredge interval (see Map 2-3).

BBP: butyl benzyl phthalate
BEHP: bis(2-ethylhexyl) phthalate
cPAH: carcinogenic polycyclic aromatic hydrocarbon
COC: contaminant of concern
cPAH: carcinogenic polycyclic aromatic hydrocarbon
FNC: Federal Navigation Channel
HCB: hexachlorobenzene
HPAH: high-molecular-weight polycyclic aromatic hydrocarbons
LPAH: low-molecular-weight polycyclic aromatic hydrocarbons
PAH: polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
PDI: Pre-Design Investigation
RAO: remedial action objective
SVOC: semivolatile organic compound
TOC: total organic carbon

2.1.2.2 Analytical Laboratory Deviations from the QAPP

Analytical laboratory deviations from the methods and procedures provided in the QAPP (Windward and Anchor QEA 2022) are described herein. Data were determined to be acceptable for use as qualified. Phase I deviations included the following:

- The certified reference material for sample delivery group (SDG) 22L0459 SVOCs was lost due to a cracked tube. The laboratory control sample and matrix spike/matrix spike duplicate were used to assess accuracy.
- Sample LDW23-SS1128 was re-analyzed for analytes with concentrations that exceeded the instrument calibration range. The diluted sample was analyzed past the 40-day holding time. The sample results were J-qualified.
- 11 samples (Tier 2 SDG 23F0143) were analyzed for TOC past the 6-month holding time.

2.1.2.3 Data Validation Results

Independent data validation was performed on all analytical chemistry results by Ecochem, Inc. Stage 4 validation was performed on a minimum of 10% of the data or a single SDG, as specified in the QAPP (Windward and Anchor QEA 2022). Stage 2B validation review was conducted on the remaining datasets.

The data validation report, which is included in the data package provided to EPA and posted to https://ldwg.org, includes detailed information regarding all data qualifiers. No data were rejected. The issues that resulted in the greatest number of J-qualified (estimated concentration) results are as follows.

- Calibration verification percent differences were greater than acceptance criteria for individual EPA 8270E SVOC compounds (40 of 45 SDGs) and EPA 8270E-SIM SVOC compounds (44 of 48 SDGs).[4]
- Laboratory replicate relative percent differences were greater than acceptance criteria for individual EPA 6020 metals (22 of 46 SDGs) and individual EPA 8270E SVOC compounds (17 of 45 SDGs).

2.1.3 Sediment Chemistry Results

Sediment data in the PDI dataset were compared with RALs presented in ROD Table 28 (EPA 2014), and cPAH results were compared with RALs presented in the cPAH ESD (EPA 2021), in order to

[4] Calibration verification differences are often observed in the analysis of complex matrices, such as sediment, when the methods used involve large numbers of analytes (e.g., EPA 8270 methods).

delineate RAL exceedance areas. A summary of RAL exceedances in the PDI dataset is presented in Table 2-5. The full design dataset is discussed in Section 3.2.

Table 2-5
Summary of RAL Exceedances in the Phase I PDI Dataset

Contaminant	Counts by Interval in the PDI Dataset[1]							
			Subsurface Sediment					
	Surface Sediment (0–10 cm)		Intertidal (0–45 cm)		Subtidal (0–60 cm)		Shoaling Intervals (variable depth)[2]	
	No. > RAL/Total	%	No. > RAL/Total	%	No. > RAL/Total	%	No. > RAL/Total	%
Human Health COCs								
Total PCBs	33/258	13	6/69	8.7	12/129	9.3	20/62	32
Arsenic	2/242	0.8	4/69	5.8	0/58	0	0/62	0
cPAHs	2/241	0.8	0/69	0	0/58	0	0/62	0
Dioxins/furans	3/52	5.8	2/23	8.7	2/9	22	0/15	0
Benthic COCs (with RAL Exceedances)[3]								
Metals								
Copper	1/242	0.4	0/5	0	0/58	0	0/62	0
Lead	1/242	0.4	0/5	0	0/58	0	0/62	0
Mercury	1/243	0.4	0/5	0	1/58	1.7	2/62	3.2
Zinc	4/242	1.7	0/5	0	0/58	0	0/62	0
PAHs								
Individual PAHs	5/241	2.1	0/5	0	1/58	1.7	0/62	0
Phthalates								
BEHP	0/238	0	1/5	20	0/58	0	0/62	0
BBP	2/238	0.8	1/5	20	0/58	0	0/62	0
Other SVOCs								
1,2,4-Trichlorobenzene	2/238	0.8	1/5	20	0/58	0	0/62	0
1,2-Dichlorobenzene	1/238	0.4	1/5	20	0/58	0	0/62	0
1,4-Dichlorobenzene	2/238	0.8	1/5	20	0/58	0	0/62	0
HCB	0/239	0	0/5	0	1/58	1.7	0/62	0
Phenol	30/238	13	0/5	0	0/58	0	0/62	0

Notes:
1. Sample counts include PDI samples submitted for analysis through May 2023 and do not include field duplicates.
2. Shoal interval samples consisted of shoaled material from the FNC and sediment from the overdredge interval (see Map 2-3)
3. PCBs and arsenic are also benthic COCs but are counted separately under human health COCs. Benthic COCs shown here are those with RAL exceedances in the PDI dataset.
BBP: butyl benzyl phthalate
BEHP: bis(2-ethylhexyl) phthalate
COC: contaminant of concern

cPAH: carcinogenic polycyclic aromatic hydrocarbon
FNC: Federal Navigation Channel
HCB: hexachlorobenzene
PAH: polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
PDI: Pre-Design Investigation
RAL: remedial action level
SVOC: semivolatile organic compound

2.1.4 Field Observations and Sediment Grain Size Results

Field observations of the surface samples and subsurface sediment cores collected during Phase I are provided in the Phase I data package posted on https://ldwg.org. Visually distinct layers of silt and sand were observed in 13 of 49[5] (27%) intertidal 0- to 45-cm samples and in 25 of 129 (19%) subtidal 0- to 60-cm samples. In general, the cores were homogenous.

In the FNC, deeper cores with more sample intervals were collected to characterize the shoaled material, as well as the 2-feet interval below the shoaled material (i.e., the overdredge interval) and another 2-feet interval below that (i.e., the Z-layer interval). The depositional material in the shoal cores was also generally homogeneous, although visually distinct layers of silt and sand were observed in 3 of 39 (8%) shoal cores.

Grain size testing was conducted on 1 interval in each of the 19 shoaling cores with a RAL exceedance. Specific percentages of gravel, sand, silt, and clay detected in samples analyzed for grain size were as follows:

- Gravel: average of 0.1% (range of 0–0.6%)
- Sand: average of 22% (range of 4–39%)
- Silt: average of 61% (range of 46–71%)
- Clay: average of 17% (range of 12–25%)

The grain size results by sample are provided in the Phase I data package posted on https://ldwg.org. A summary of these results and the locations of the grain size samples are presented on Map 2-4.

2.2 Bank Visual Inspection

LDW middle reach banks are defined as the transitional area from the LDW subtidal or intertidal sediment bed to the upland areas above MHHW. A bank is typically delineated as starting at the toe, where the relatively flat waterway bed (which varies in elevation) begins to slope steeply to the top of bank (i.e., the area where the slope flattens in the upland, above MHHW). The toes of banks vary significantly in elevation, because banks are adjacent to various shorelines in the LDW (e.g., next to berthing or navigation areas [with toe of bank elevation controlled by navigation needs] or adjacent to intertidal mudflats).

[5] Hand-collected intertidal subsurface sediment samples are not included in this count.

2.2.1 Methods

The Phase I bank visual inspection was conducted to address DQO 8 (Table 1-2), building upon the results of the LDW waterway user survey (Integral et al. 2018) by collecting additional details to support engineering design. Maps 2-5a through 2-5e show updated bank type classifications based on Phase I visual observations.

Based on visual observations, banks along the middle reach have been broadly classified as armored, unarmored, or bulkheaded, consistent with the LDW waterway user survey (Integral et al. 2018). Section 2.1.7 of the RDWP (Anchor QEA and Windward 2022b, 2019) defines armored banks as having an engineered surface armoring (e.g., riprap armoring, gabion armoring, bulkhead [sheetpile, concrete]) to prevent bank erosion. Unarmored banks have no armoring or poorly placed or maintained armoring such that significant gaps in armoring exist (e.g., banks with intermittently exposed sediment/soil). Vegetated banks are included in the unarmored category. Bulkheaded banks most frequently occur coincident with overwater structures and are supported by armored slopes.

Based on observations during the Phase I inspection, the armored category was divided into two subcategories: engineered and semi-engineered. The semi-engineered bank areas include shoreline slopes that, while covered with armoring materials, clearly are not engineered or constructed of rock armoring material (e.g., riprap). The material present on most semi-engineered banks appears to be integral to overall bank stability; these areas will require additional evaluation if they are located adjacent to or within RAL exceedance areas.

Phase I inspections were performed from the toe to the top of bank. The toe of an armored bank is defined as the start of the armor material. The toe of a bulkhead is defined as the point where the vertical bulkhead meets the adjacent sediment or soil surface below the bulkhead. The toe of an unarmored bank is defined as the point where the relatively flat waterway bed (which varies in elevation) begins to slope steeply to the top of bank. The top of a bank is the point at which the slope transitions to a flatter elevation similar to that of the adjacent uplands. Although the waterway user survey also defined “dock faces” as a distinct type of bank (Integral et al. 2018), this classification is not being carried forward to characterize banks for RD. “Dock faces” herein refer to overwater structures, which are covered in Section 2.3.

In addition to the broad bank type classifications, detailed observations were documented noting the presence of the following features (as applicable[6]), per the QAPP (Windward and Anchor QEA 2020):

- Type of armoring material

[6] While the visual bank inspection was conducted at low tide to maximize observations, this timing also limited the ability of the inspection vessel to get close to the shoreline. Therefore, some features were difficult to document, including potential discharges from outfalls at the time of the survey. These features will be further investigated during Phase II PDI if they are adjacent to or within a RAL exceedance area.

- Estimated slope/grade
- Presence of sediment accumulated on armored slopes
- Bank erosion
- Utility crossings
- Outfalls/pipes
- Discharge flowing from outfalls
- Navigational obstructions
- Access points

Two field deviations from the PDI QAPP (Windward and Anchor QEA 2020) occurred during the bank visual inspection. One was related to the method of documenting visual observations, and the other was related to access to shoreline areas. A new field form was created to document visual observations. This form includes figures of FNC stationing, infrastructure information, and any recent aerial photographs, allowing observations to be handwritten directly on figures to better tie observations to locations. This field deviation did not affect data quality and enabled the field team to more accurately and efficiently collect field data.

The second deviation was related to access limitations in three areas: 1) the eastern shoreline at Duwamish Marine Center (approximately at RM 1.95), 2) the inlet below the west span of the 1st Avenue South Bridge, and 3) the inlet at RM 2.2W. Because the field crew could not access these areas via boat because of obstructions or low tide conditions, remote photograph techniques were used to obtain visual information for the shoreline areas. The photographs were subsequently reviewed and documented on the shoreline visual inspection forms. As necessary, these areas will be investigated further during Phase II to complete shoreline documentation.

The PDI QAPP (Windward and Anchor QEA 2020) did not specify a stationing approach to record observations. In lieu of establishing a reach-specific stationing system, shoreline visual observations along the main waterway were related to FNC stationing and associated river mile. This decision was based on lessons learned from the LDW upper reach RD. The locations of visual observations made in Slips 2 through 4 are based on distance from the northernmost point of the shoreline, adjacent to the main waterway. As such, these observations begin on the waterway end of the northern banks and run clockwise around the embayment.

2.2.2 Results

The Phase I bank visual inspection was conducted primarily by boat around daytime low tides (two hours before and two hours after) on June 5 and 6, 2023. According to observations from that inspection, approximately 52% of the middle reach bank areas are armored, 19% are bulkheaded with an armored slope, 23% are unarmored, and 6% are vertical bulkheaded. Detailed observations are documented in Appendix A. Shoreline observations are summarized graphically on Maps 2-5a through 2-5e. Select photographs from the bank visual inspection are included in Appendix A. Additional photos can be provided to EPA upon request.

Vessel access for PDI investigations in some Phase II PDI bank sampling areas will be limited due to shallow water conditions. Access from the uplands is generally possible, although some bank areas are over-steepened or heavily vegetated, and sampling equipment access may be difficult in some areas. The most challenging area to access is the Duwamish Marine Center (approximately RM 1.95E). Manual coring techniques will likely be required at this location. No unique safety concerns that would prohibit bank characterization were noted for specific bank areas, with the exceptions of the Seattle Iron and Metals South Wharf.

2.3 Structures Visual Inspection

The Phase I structures visual inspection was conducted on August 8, 2022 to support DQO 8 (as described in Section 5.2 of the PDI QAPP (Windward and Anchor QEA 2022)). The inspection results confirmed and supplemented data regarding identified structures and observations in the existing waterway user survey (Integral et al. 2018). The inspection also provided additional information, including any discrepancies or changed conditions, to support engineering design. The inspected structures consisted of overwater structures (wharfs, piers, docks, etc.), in-water structures (piles, pile groups, dolphins, berths, etc.), and other shoreline structures (bulkheads, wing walls, etc.).

The Phase I structures visual inspection was performed by the dive supervisor and the engineering team, including the structural engineer, to verify the general stability of each structure and whether the areas beneath them can be accessed safely. At this time, only one structure has been identified as unsafe—the southern Seattle Iron and Metals wharf at RM 2.55E. The structure inspections are documented in Appendix B.

2.4 Phase I Bathymetric Surveying

Several bathymetric surveys were performed during the Phase I PDI to fill data gaps remaining from the 2021 bathymetric survey, the results of which were presented in Appendix B to the PDIWP (Windward and Anchor QEA 2020). Appendix C of this DER contains the PDI Bathymetric Survey Data Report prepared by Northwest Hydro. Remaining data gaps cannot be resolved using bathymetric surveying equipment. They will be identified in an addendum to the survey QAPP (Anchor and Windward 2019), along with an approach to fill the data gaps.

The Phase I PDI bathymetric surveys required close coordination with middle reach waterway users and adjacent property owners. The bathymetric surveys were performed between January and June 2023, by Northwest Hydro, which also performed the 2021 bathymetric survey. The equipment and methods used to perform the Phase I surveys were the same as those used for the 2021 bathymetric survey, per the survey QAPP (Anchor and Windward 2019). The precision and accuracy of the two surveys were the same and yielded compatible data. There were no deviations from the survey QAPP. The key targets and related data for the 2021 and Phase I surveys are summarized in Table 2-6.

Table 2-6
Key Targets and Related Datums for Bathymetric Surveying

Description	Quantity or Datum
Horizontal positioning accuracy	1.6 feet minimum
Horizontal survey accuracy	3 feet at a 95% confidence interval
Horizontal datum	North American Datum of 1983/1991 Washington North Zone
Vertical survey accuracy	+/- 0.5 feet at a 95% confidence interval
Vertical datum	MLLW

Notes:
Source: Table 3 of the survey QAPP (Anchor and Windward 2019).
MLLW: mean lower low water
QAPP: quality assurance project plan

An updated bathymetric surface for the middle reach was created by combining the multiple Northwest Hydro bathymetric surveys (Map 2-6). The complete, combined bathymetric survey is referred to as the PDI Bathymetric Survey in this DER and in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b).

2.5 Inadvertent Discovery Plan Implementation

An archaeological monitoring and inadvertent discovery plan was developed to address the potential for any unanticipated discovery of cultural resources, artifacts, or other archaeological features during sampling activities. The plan, included as Attachment B of the middle reach PDI QAPP (Windward and Anchor QEA 2022), described the locations where archaeological monitoring was required and provided direction, contact information, and procedures to follow should an inadvertent discovery occur.

During the Phase I PDI, Stell Environmental Enterprises performed archaeological monitoring throughout the sampling program from December 2022 through May 2023. No significant cultural resources were encountered during monitoring.

3 Data Evaluation

This section presents the datasets used to derive the design dataset, a count of RAL exceedances in the design dataset, the recovery category assessment, and the delineation of RAL exceedance areas based on the design dataset.

3.1 Design Dataset

The middle reach design dataset includes sediment data from the Phase I PDI and pre-PDI data from the remedial investigation/feasibility study (RI/FS) and post-FS sampling events, as defined in Section 3.1 of the PDIWP (Windward and Anchor QEA 2023). Data in the design dataset have been used to define RAL exceedance areas. A detailed description of the data management rules used to create the design dataset is presented in Appendix D.

Table 3-1 shows how many sampling locations were contributed by the RI/FS, post-FS, and Phase I PDI to the design dataset for each of the RAL sediment depth intervals.

Table 3-1
Number of Middle Reach Design Dataset Locations with RAL Intervals by Data Source

Dataset	Date Range	No. of Surface Sediment Locations (0–10 cm)	Subsurface Sediment Locations		No. of Shoal Core Locations
			No. of Intertidal (0–45 cm)	No. of Subtidal (0–60 cm)	
RI/FS	1990–2010	0	0	16	1
Post-FS	2010–2021	214	1	10	7
PDI (Phase I)	2022–2023	259	69	129	39
Total		**473**	**70**	**155**	**47**

Notes:
FS: feasibility study
PDI: Pre-Design Investigation
RAL: remedial action level
RI: remedial investigation

3.2 Comparison of Design Dataset with RALs

In order to delineate RAL exceedance areas, sediment data in the design dataset were compared with RALs presented in ROD Table 28 (EPA 2014), and cPAH results were compared with RALs presented in the cPAH ESD (EPA 2021). A summary of RAL exceedances in the design dataset is presented in Table 3-2. RAL exceedances are shown by location on Maps 3-1a through 3-1e; these maps also show RAL exceedance areas, which are discussed in Section 3.4.

Table 3-2
Summary of RAL Exceedances in the Middle Reach Design Dataset

COC	Counts by Interval[1]								Total Counts	
	Surface (0–10 cm)		Subsurface (0–45 cm)		Subsurface (0–60 cm)		Shoal Intervals (depth varies)[2]			
	No. > RAL/ Total	%	No. > RAL/ Total	%	No. > RAL/ Total	%	No. > RAL/ Total	%	No. > RAL/ Total	%
Human Health COCs										
PCBs	64/441	15	7/70	10	17/153	11	33/81	41	121/745	16
Dioxins/furans	11/128	9	2/23	9	2/10	20	2/32	6	17/193	9
Arsenic	6/422	1	4/69	6	0/62	0	0/81	0	10/634	2
cPAHs[3]	4/407	1	0/69	0	0/62	0	0/81	0	4/619	0.6
Benthic COCs (with RAL Exceedances)[4]										
Metals										
Chromium	4/422	0.9	0/5	0	0/62	0	0/81	0	4/570	0.7
Copper	1/384	0.3	0/5	0	0/62	0	0/81	0	1/532	0.2
Lead	1/422	0.2	0/5	0	0/62	0	0/81	0	1/570	0.2
Mercury	4/422	0.9	0/5	0	1/62	2	2/81	2	7/570	1
Zinc	7/384	2	0/5	0	0/62	0	0/81	0	7/532	1
PAHs										
Individual PAHs[5]	8/408	2	0/5	0	2/62	3	0/81	0	10/556	2
Other SVOCs										
1,2,4-Trichlorobenzene	2/368	0.5	1/5	20	0/62	0	0/81	0	3/516	0.6
1,2-Dichlorobenzene	1/368	0.3	1/5	20	0/62	0	0/81	0	2/516	0.4
1,4-Dichlorobenzene	2/368	0.5	1/5	20	0/62	0	0/81	0	3/516	0.6
2,4-Dimethylphenol	1/368	0.3	0/5	0	0/62	0	0/81	0	1/516	0.2
Benzoic acid	2/368	0.5	0/5	0	0/62	0	0/81	0	2/516	0.4
Hexachlorobenzene	0/368	0	0/5	0	2/62	3	0/80	0	2/515	0.4
Phenol	30/368	8	0/5	0	0/62	0	0/81	0	30/516	6
Phthalates										
BEHP	4/368	1	1/5	20	0/62	0	0/81	0	5/516	1
BBP	5/368	1	1/5	20	0/62	0	0/81	0	6/516	1
Dimethyl phthalate	1/368	0.3	0/5	0	0/62	0	0/81	0	1/516	0.2

Notes:
1. The design dataset includes samples from the pre-PDI and PDI datasets. Sample counts include PDI samples submitted for analysis through May 2023.
2. Shoal interval samples consisted of shoaled material from the FNC and sediment from the overdredge interval (see Map 2-3).
3. cPAH results are compared with the RALs presented in the cPAH ESD (EPA 2021). See Appendix H for a comparison of cPAH results with the 2014 ROD RALs (EPA 2014).
4. PCBs and arsenic are also benthic COCs but are counted separately under human health COCs. Benthic COCs shown here are those with RAL exceedances in the design dataset.

5. Counts include exceedances of one or more of the following PAHs: acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, total benzofluoranthenes, benzo(g,h,I)perylene, chrysene, dibenzo(a,h)anthracene, dibenzofuran, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, phenanthrene, pyrene, total HPAHs, or total LPAHs.
BBP: butyl benzyl phthalate
BEHP: bis(2-ethylhexyl) phthalate
COC: contaminant of concern
cPAH: carcinogenic polycyclic aromatic hydrocarbon
ESD: explanation of significant differences
FNC: Federal Navigation Channel
HPAH: high-molecular-weight polycyclic aromatic hydrocarbon
LPAH: low-molecular-weight polycyclic aromatic hydrocarbon
PAH: polycyclic aromatic hydrocarboni
PCB: polychlorinated biphenyl
PDI: Pre-Design Investigation
RAL: remedial action level
ROD: Record of Decision SVOC: semivolatile organic compound

Key takeaways from Table 3-2 include the following:

- **PCBs** – PCBs were the primary contaminant of concern (COC) in the middle reach with the most RAL exceedances. Concentrations of PCBs were greater than the RAL in 16% of samples in the design dataset across all sample types.
- **Other COCs** – Additional COCs with at least one RAL exceedance in the design dataset included dioxins/furans, six metals (arsenic, chromium, copper, lead, mercury, and zinc), polycyclic aromatic hydrocarbons (PAHs) (14 individual PAHs, total high-molecular-weight polycyclic aromatic hydrocarbons [HPAHs], total low-molecular-weight polycyclic aromatic hydrocarbons [LPAHs], and cPAHs), seven other SVOCs (1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, 2,4-dimethylphenol, benzoic acid, hexachlorobenzene, and phenol), and three phthalates (bis(2-ethylhexyl) phthalate [BEHP], butyl benzyl phthalate [BBP], and dimethyl phthalate). These COCs exceeded the RAL in 0.2% to 8.8% of the design dataset samples.
- **Surface samples** – The majority of surface RAL exceedances were for PCBs; there were PCB RAL exceedances in 15% of surface sediment samples in the design dataset. In addition, there were dioxin/furan RAL exceedances in 8.6% of the subset[7] of surface sediment samples analyzed for dioxin/furans, and there were phenol RAL exceedances in 8.2% of surface sediment samples. Other COCs exceeded the RALs in surface sediment in 0.2% to 2.0% of the design dataset.
- **Subsurface samples** – The majority of subsurface RAL exceedances were for PCBs and dioxins/furans; there were RAL exceedances in 11% (24 of 223 samples) and 12% (4 of 33 samples) (respectively) of the subsurface samples (both intertidal and subtidal areas, not including shoaling cores). Other COCs exceeded the subsurface RALs in 1.5% to 3.1% of the design dataset. Other COCs with concentrations greater than subsurface RALs were arsenic,

[7] As described in the PDI QAPP (Windward and Anchor QEA 2022), a subset of Phase I samples were analyzed for dioxins/furans, generally targeting areas with elevated dioxin/furan TEQs.

mercury, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, hexachlorobenzene, BEHP, and BBP.

- **Shoaling samples** – The majority of RAL exceedances in subsurface shoaling core samples (including shoal and overdredge interval samples) were for PCBs (41% of the analyzed shoaling samples had concentrations that exceeded the RAL for PCBs). Other COCs with concentrations greater than RALs in shoaling samples included mercury (two samples) and dioxins/furans (two samples in the subset analyzed for dioxin/furans).

3.3 Recovery Category Assessment

Recovery category areas were developed in the FS (AECOM 2012) and subsequently re-assessed and revised in the *Recovery Category Recommendations Report* (Integral et al. 2019) and in Appendix C of the PDIWP (Windward and Anchor QEA 2023). Recovery categories are used to help identify the spatial application of RALs and remedial technologies (EPA 2014). Generally, Recovery Category 1 designates areas where only dredging and/or capping are applicable; Recovery Categories 2 and 3 designate areas where monitored natural recovery (MNR), enhanced natural recovery (ENR), dredging, and capping are all applicable.

Per Section 3.4 of the RDWP (Anchor QEA and Windward 2022b), the recovery category assignments were re-assessed in portions of the middle reach that were surveyed during the Phase I PDI to fill in missing survey coverage from the 2021 bathymetric survey. Based on the bathymetric survey analysis, one change was warranted: Recovery Category 2 within the subtidal area along the eastern shoreline between RM 2.25 and RM 2.3 should be changed to Recovery Category 1 (Map 3-2). See Appendix E, Table E2-1 for additional information.

In addition, the recovery category areas in the middle reach were re-assessed for this DER by comparing the chemistry data collected during the Phase I PDI to data collected previously at locations that were reoccupied (i.e., resampled within 10 feet of the original location). No changes in recovery categories are warranted based on the chemistry comparison (Appendix E).

3.4 Areas with RAL Exceedances and Preliminary Technology Assignments

This section presents the preliminary delineation of areas with RAL exceedances using the middle reach design dataset. Preliminary technology assignment options for each area are also presented in this section.

3.4.1 Defining Areas with RAL Exceedances

One of the primary objectives of this Phase I DER is to delineate areas with RAL exceedances using the design dataset. Delineation at this point in the design process provides an indication of where remediation will occur and also serves to identify Phase II data gaps so RAL exceedance areas can be further refined and vertical extent cores can be collected to support the design.

Spatial data interpolation methods were used to delineate areas with RAL exceedances to serve as the foundation for 30% RD, and to establish the initial horizontal extent of the RD footprint. Interpolation uses a local neighborhood of surrounding data points to estimate the values at all unsampled points in the map domain. Interpolation is a standard method used in RD to define areas requiring remedial action (e.g., Anchor QEA 2014; Anchor QEA and Tetra Tech 2016; City of Tacoma 2002; Thornburg et al. 2005).

Appendix F provides a detailed presentation of the interpolation methods and their application in the middle reach, including PCB spatial correlation structures and interpolation results, an uncertainty analysis using multiple lines of evidence to assess confidence in the PCB RAL exceedance area boundaries, and RAL exceedance area maps for PCBs and other COCs to support RD. The rest of this section provides a summary of the analyses and results presented in Appendix F.

3.4.1.1 Interpolation Methods

PCBs were selected as the primary COC for detailed numerical data interpolation, because PCBs delineate a majority[8] of the RAL exceedance areas in the middle reach. Other COCs exceeding RALs in localized areas were evaluated separately, and the results for all COCs were combined with the PCB results in the final RAL exceedance area footprint.

Interpolations were performed on two sediment depth-defined datasets applicable to RALs: surface sediment, defined as 0 to 10 cm; and subsurface sediment, defined as 0 to 45 cm in intertidal areas, 0 to 60 cm in subtidal areas, and shoaling intervals in the FNC.[9] Using a GIS raster computation, the interpolations of surface and subsurface sediment were merged into a single map showing the combined exceedance footprint of both surface and subsurface layers.

During RD for the upper reach, exploratory spatial data analysis was performed to support selection of a preferred interpolation method (see *Pre-Design Investigation Data Evaluation Report for the Lower Duwamish Waterway Upper Reach*, Appendix K (Anchor QEA and Windward 2022a)). Based on the results of this analysis, indicator kriging was selected as the interpolation method for PCBs, and Thiessen polygons was selected as the interpolation method for secondary COCs that extend beyond the PCB RAL exceedance boundary. Given the similarities of waterway processes and contaminants,

[8] Based on the results of the interpolation work described in this section, PCBs were estimated to account for 76% of the RAL exceedance area in the middle reach. This percentage was calculated as the ratio of interpolated RAL exceedance area circumscribed by PCBs (in acres or square feet) to the total RAL exceedance area circumscribed by all COCs (excluding phenol-only exceedance areas, which may be transient and are being further investigated in the Phase II PDI; see Maps F-6a and F-6b in Appendix F).

[9] The maximum concentration in any shoaling interval or the overdredge interval (i.e., 2 feet below authorized FNC depth) was selected for each shoaling core location.

and to be consistent with the RD of the upper reach, these same interpolation methods were applied in the middle reach.

3.4.1.1.1 Indicator Kriging

Indicator kriging was selected as the preferred method for PCB interpolation for several reasons: 1) indicator kriging provides quantitative estimates of the uncertainty of the RAL exceedance area boundaries; 2) indicator kriging is a nonparametric method that does not require the data to conform to a normal distribution; 3) indicator kriging can readily accommodate mixed units, specifically, mixed organic carbon-normalized and dry weight concentrations and RALs; and 4) indicator kriging has been successfully applied to support RD and remedial action on other large sediment sites (Anchor QEA and Tetra Tech 2016; Thornburg et al. 2005; Wolfe and Kern 2008; EPA 2022), including the upper reach of the LDW (Anchor QEA and Windward 2022a).

3.4.1.1.2 Thiessen Polygons

Although PCB exceedances delineated the majority of contamination in the middle reach, in localized areas, the RAL exceedance area boundaries were expanded where other COCs exceeded RALs but PCBs did not. Because these areas were more localized, the RAL exceedance area boundaries for COCs other than PCBs were established using Thiessen polygons, a simpler geometric and deterministic interpolation method. Other COCs that determined local RAL exceedance area boundaries included metals, PAHs, other SVOCs (BEHP, BBP, benzoic acid, dibenzofuran, 2,4-dimethylphenol, phenol, chlorobenzenes), and dioxins/furans, depending on the area.

Thiessen polygons for phenol are shown in blue on Maps 3-1a through 3-1e. These polygons show the locations and interpolated extents of the 30 surface sediment samples with phenol RAL exceedances in the Phase I PDI. Phenol is an aromatic organic alcohol that is a natural product of the decomposition of organic matter and the burning of wood and petroleum products (ATSDR 2008). Phenol is also commercially produced as a precursor to the production of epoxy resins and as a general disinfectant. It is readily biodegradable, with a half-life in soil of fewer than five days; high solubility in water (with an aqueous solubility of 80,000 mg/kg); and a relatively low affinity for particulate organic carbon, with log K_{OC} values ranging from 1.2 to 1.9 (ATSDR 2008).

Elevated phenol concentrations are not common in the LDW (Windward 2010). There were no phenol RAL exceedances in the middle reach design dataset prior to the Phase I investigation (Windward and Anchor QEA 2023), and only one surface sediment sample exceeded the phenol RAL in the upper reach design dataset (Anchor QEA and Windward 2023a).

Phenol concentrations greater than the benthic SCO were reported in the long-term monitoring dataset for the Duwamish Diagonal sediment remediation. Surface sediment was collected annually for nine years (2004–2012) from 23 locations in the vicinity of the Duwamish/Diagonal Way combined sewer overflow/storm drain outfall to characterize surface sediment in two cap areas, an ENR area, and the surrounding perimeter (King County 2015, 2016). Phenol concentrations exceeded the benthic SCO at a subset of sampling locations in samples collected in three non-consecutive years (2008, 2010, and 2012). The fact that the phenol exceedances did not persist from one year to the next is consistent with the chemical fate of phenol and the transient nature of this compound.

Based on chemical fate and prior sediment time series data from the LDW, phenol is not expected to be persistent in the aquatic environment or in sediment. The persistence of the Phase I phenol exceedances will be further investigated as part of the Phase II PDI, as described in the PDI QAPP Addendum for Phase II. Pending the results of that investigation, phenol Thiessen polygons are shown separately from RAL exceedance areas (Map 3-3) and are not included in the numbered RAL exceedance areas for remedial technology assignment discussed in Section 3.4.2.

3.4.1.2 Interpolation Results and Uncertainty Analysis

RAL exceedance areas based on indicator kriging for PCBs and Thiessen polygons for other COCs are presented on Maps 3-1a through 3-1e, on Map 3-3, and in Appendix F. In Appendix F, Maps F-3a/b, F-4a/b, and F-5a/b show surface sediment, subsurface sediment, and combined surface and subsurface sediment PCB RAL exceedance areas, respectively. The indicator kriging contours represent the probabilities of exceeding the applicable RALs, expressed in units of percent. The 50% probability of exceedance contour represents the median or central tendency estimate of the horizontal RAL exceedance boundary. Other probability contours are provided in the Appendix F map folio, including the 20%, 30%, 40%, 50% (median), 60%, 70%, and 80% probabilities of exceedance. Maps 3-1a through 3-1e and Map 3-3show the median (50%) PCB RAL exceedance boundary overlain with Thiessen polygons for other COCs that extend beyond the median PCB boundary. As noted, Thiessen polygons for phenol-only exceedances are delineated separately because of the demonstrated transient and ephemeral nature of phenol in LDW sediments and the potential for natural sources. Additional investigation of phenol contamination is planned, as described in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b).

The uncertainty of the PCB RAL exceedance area boundary was assessed using three independent lines of evidence: 1) indicator kriging probability contours, 2) assessment of analytical uncertainty, and 3) sensitivity analysis of nugget and range values. Indicator kriging provides direct, quantitative, probabilistic information and is the primary line of evidence for assessing the uncertainty of the PCB RAL exceedance boundary. The results of these assessments, which are discussed in Appendix F, confirm that the selected interpolation methodology is appropriate to support RD in the middle reach.

The median indicator kriging boundary, which corresponds to the 50% probability of exceedance, is recommended as the beginning basis for RD. In the LDW upper reach (Anchor QEA and Windward

2022a) and on the Fox River and Hudson River sediment cleanup sites (Anchor QEA and Tetra Tech 2016; Kern et al. 2008; Wolfe and Kern 2008; QEA 2007), the median kriging estimate was used similarly to define the RD remediation boundary. In these instances, the estimate was shown to provide a reasonable balance between effectively removing contaminated sediment with concentrations above the RALs and excluding sediment with concentrations below the RALs. During the design process, the remediation footprint in many areas is expanded beyond the median boundary to address engineering and constructability considerations. Thus, a greater level of confidence will be achieved after design of the RAAs is complete.

Best professional engineering judgment may be used to address locations with greater uncertainty by adjusting RAA boundaries during RD, and/or by identifying the need for Phase II data to reduce uncertainties in particular areas. Recommended Phase II sampling locations—including those aimed at reducing the uncertainty of RAL exceedance area boundaries—are presented in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b).

In total, as a result of interpolation, 34 RAL exceedance areas were identified (Map 3-3); these areas are shown relative to the design dataset in Maps 3-1a through 3-1e. The areas shown include areas with RAL exceedances and interpolation-only areas.[10] Thiessen polygons for phenol as shown separately pending the results of the Phase II PDI.

3.4.2 Preliminary Remedial Technology Assignment Options

Figures 19 and 20 in the ROD[11] describe the process by which remedial technologies are to be assigned during the RD process. A variety of factors govern the preliminary selection of applicable remedial technologies, including mudline elevation, RAL exceedance factor, depth of contamination, and recovery category designation.

There are different remedial technologies that may be applicable in each area with RAL exceedances, and these may conflict with each other from a constructability standpoint. Therefore, the final remedial technology assignment within each area will be determined during RD by factoring in engineering and constructability considerations, in order to develop a constructable, stable, and protective design.

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

[11] Figure 20 was corrected after the ROD was published (EPA 2014). Reference to Figure 20 herein refers to the corrected version, which was published in a memorandum from EPA dated August 26, 2015 (EPA 2015).

Potential remedial technologies identified in the ROD (EPA 2014) for intertidal and subtidal areas include the following:

- Intertidal:
  - MNR
  - Area-specific technology[12]
  - ENR
  - PD&C
  - Dredge and backfill
- Subtidal:
  - MNR
  - Area-specific technology
  - ENR
  - Dredge (with backfill in habitat areas)[13]
  - Cap or armored cap

Preliminary technology assignments for each RAL exceedance area are described in Appendix G and summarized in Table 3-3. Note that a given RAL exceedance area may have more than one subareas, each with a different preliminary remedial technology assignment.

Table 3-3
Preliminary Technology Assignment Options by RAL Exceedance Area

RAL Exceedance Area	Preliminary Technology Assignment Options1					Notes
	Dredge	PD&C	Cap	ENR	AST	
1	•			•		ENR potentially suitable outside Recovery Category 1 area
2	•					--
3					•	Area primarily below overwater structure
4	•	•				
5	•	•		•	•	Area partially below overwater structure; ENR potentially suitable north of pier
6	•	•	•			Capping potentially suitable below subtidal habitat area

[12] In areas with structural or access restrictions, area-specific cleanup technologies will be applied as described in ROD Section 13.2.1.3 (EPA 2014).
[13] Habitat areas were defined in the FS as all areas above -10 feet mean lower low water (MLLW).

RAL Exceedance Area	Preliminary Technology Assignment Options1					Notes
	Dredge	PD&C	Cap	ENR	AST	
7	•	•	•			Capping potentially suitable below subtidal habitat area
8	•			•		--
9	•	•	•		•	Area includes Georgetown Steam Plant Pump Station; capping potentially suitable below subtidal habitat area
10	•	•				--
11	•	•			•	Area adjacent to structurally compromised structure
12	•	•				--
13	•	•	•			Capping potentially suitable below subtidal habitat area
14	•				•	Area partially below overwater structure
15	•	•			•	Area adjacent to steep, potentially unstable slope
16	•	•				--
17	•	•				--
18	•	•	•			Capping potentially suitable below subtidal habitat area
19	•			•		--
20	•	•			•	Inlet at RM 2.2W
21	•	•		•	•	Area-specific technology may apply due to adjacent structure(s); ENR potentially suitable north of pier
22	•	•				--
23					•	Area under overwater structure
24	•	•			•	Area-specific technology may apply due to adjacent structure(s) and steep, potentially unstable slope
25	•	•	•	•		ENR and capping potentially suitable outside of berth area
26	•	•	•		•	Adjacent to 1st Ave South Bridge; capping potentially suitable below subtidal habitat area
27	•	•	•		•	Adjacent to 1st Ave South Bridge and public boat launch; capping potentially suitable below subtidal habitat area
28	•	•			•	Adjacent to 1st Ave South Bridge
29	•	•			•	Area-specific technology may apply due to adjacent structure(s)
30	•	•		•	•	Area partially below overwater structure
31	•			•		--

RAL Exceedance Area	Preliminary Technology Assignment Options1					Notes
	Dredge	PD&C	Cap	ENR	AST	
32	•	•				--
33	•	•				--
34	•	•				--

Notes:
1. Where multiple technology assignments are listed, either more data are needed to finalize the technology assignment, or different technologies apply over different portions of the area. Backfill is required above -10 feet MLLW.
AST: area specific technology
ENR: enhanced natural recovery
MLLW: mean lower low water
PD&C: partial dredge and cap
RAL: remedial action level
RM: river mile

Understanding the range of applicable remedial technologies for each RAL exceedance area is necessary to identify Phase II data gaps, which can vary depending on the technologies. The Phase II QAPP Addendum discusses the data gaps that have been identified for all applicable remedial technologies in each RAL exceedance area (Anchor QEA and Windward 2023b). Additional data collected during the Phase II PDI and engineering considerations will be evaluated during 30% RD. Remedial technologies are expected to be finalized during 60% RD, pending any relevant Phase III data, which would be provided during 90% RD.

4 General Phase II Data Gaps

This section identifies general categories of data gaps to be filled by data from Phase II PDI sampling to address the Phase II identified in the PDI QAPP (Table 4-1) (Windward and Anchor QEA 2020). Detailed information regarding sediment sampling locations, depth intervals, and analytes, as well as other information to be collected in Phase II, are provided in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b). The Phase II QAPP Addendum also includes an inadvertent discovery plan describing actions related to cultural resources to be performed during the Phase II investigations.

Table 4-1
DQOs for Phase II of the PDI in the Upper Reach

Phase II
DQO10 – Further delineate RAL exceedances, as needed for unbounded areas.[1]
DQO11 – Assess chemical and physical characteristics of banks (including topographic survey), as needed, depending on remedial technology selected for adjacent sediment and whether bank is erosional.
DQO12 – Delineate vertical elevation of RAL exceedances in dredge (and dredge/cap) areas and collect subsurface sediment chemistry data in cap areas where contamination under caps will remain.
DQO13 – Collect geotechnical data as needed depending on technology proposed and/or physical characteristics of remedial action areas.
DQO14 – Collect other engineering applicable data as needed (e.g., structures inspection, utility location verification, thickness of sediment on top of riprap layers, groundwater velocities).

Notes:
1. Toxicity testing may be used to override chemical data in RAL delineation in Phase II (DQO 10), per the ROD (EPA 2014).
DQO: data quality objective
PDI: Pre-Design Investigation
RAL: remedial action level
ROD: Record of Decision

4.1 Refining Areas with RAL Exceedances (DQOs 9 and 10)

Additional data are needed to refine the horizontal extent of many of the areas with RAL exceedances currently delineated using the design dataset. General considerations for additional data, whether for surface (0- to 10-cm) or subsurface (0- to 45- or 0- to 60-cm or shoals) sampling, are summarized below.

- Collect additional data around the interpolated boundaries of areas with RAL exceedances, where needed to supplement the design dataset.
- Collect samples in RAL exceedance areas that are based on interpolated concentrations only (i.e., where subsurface RALs change based on bathymetric and recovery category boundaries). See RAL Exceedance Area 18 on Map 3-1c as an example.
- Re-occupy locations with concentrations that exceeded only benthic RALs for toxicity testing and that, if they were to pass benthic toxicity tests, would affect RAL exceedance area

boundaries; note that most of these locations are for phenol exceedances, as described in the PDI QAPP Addendum for Phase II.

- Analyze select archived Phase I samples as needed to further refine the interpolation.

4.2 Banks (DQO 11)

DQO 11 involves the characterization of armored banks, unarmored banks,[14] and vertical bulkheads located within areas with RAL exceedances. The following Phase II data gaps have been identified for banks located within areas with RAL exceedances:

- Horizontal extent of RAL exceedances
- Vertical extent of RAL exceedances (where the preliminary remedial technology assignment requires)
- Geotechnical data (see Section 4.4.), topographic data, and other engineering data (see Section 4.5), where needed

The types of data needed for RD vary based on the surface condition of the bank (e.g., armored, unarmored), its characteristics (i.e., slope, vertical bulkhead, or presence of overwater structure), and whether the RAL exceedance in the samples collected adjacent to the bank is limited to surface (0- to 10-cm) or extends to subsurface (0- to 45 or 0- to 60-cm) sediments.

Appendix A (Table A1-2) summarizes the various bank types observed in the areas with RAL exceedances and includes example photographs to illustrate each bank type. These areas will be further characterized in Phase II. Bank data collection locations and methods are presented in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b).

4.3 Vertical Delineation (DQO 12)

To address DQO 12, deep subsurface sediment data (i.e., > 60 cm) and vertical data from shoaling areas with RAL exceedances in the overdredge interval are needed from areas with RAL exceedances that may be dredged. These data will be used to delineate the vertical extent of RAL exceedances. Areas with subsurface intervals that do not exceed the RAL based on the design dataset will be considered vertically bounded for RD.

Vertical RAL exceedance delineation data are necessary in areas where dredge or PD&C are applicable technologies, so that required dredge elevations and caps (where appropriate) can be designed. Vertical RAL exceedance delineation data may also be needed at the boundary between adjacent dredge and ENR areas, to inform RD on how to transition between the two remedial

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[14] As described in the RDWP (Anchor QEA and Windward 2019) and in Section 2.2 of this document, "unarmored banks" are banks subject to erosion; they include vegetated banks and banks with debris or armor in loose, random, or poor condition (discontinuous armor).

technologies. In the FNC, vertical delineation data are needed to design dredge or PD&C remedies, in accordance with ROD Figure 20 (EPA 2014). For intertidal locations, the logic presented in ROD Figure 19 will be used to develop the vertical delineation strategy. Details regarding the vertical delineation approach for Phase II are provided in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b).

4.4 Geotechnical Data (DQO 13)

Geotechnical data are used to assess the dredgeability of sediment, evaluate the bearing capacity and settlement of caps, assess the stability of existing slopes and structures, assess the static and seismic performance of a remedial action, and design stable side slopes for dredge cuts or cap designs. Geotechnical data are a Phase II data gap within areas with RAL exceedances and, as applicable, their associated banks. The type of geotechnical data needed for engineering design differs between in-water areas and areas that abut shoreline banks.

Available geotechnical data will help inform the types and locations of recommended Phase II PDI geotechnical investigations. A description of existing geotechnical data and details regarding the geotechnical investigation approach for Phase II are provided in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b).

4.5 Other Engineering Data (DQO 14)

In addition to geotechnical investigations, there are several other categories of engineering data (DQO 14) necessary to complete RD, including:

- Structures
- Debris
- Vegetation
- Waste characterization for disposal
- Sediment thickness over armored banks

4.5.1 Structures

The design of remedial actions adjacent to structures will require additional structural engineering data that will be collected during the Phase II PDI. Where structures abut or are within areas with RAL exceedances, a more detailed structural inspection will be conducted, including collecting structure dimensions (e.g., pile diameters) and performing finer-scale visual assessments. These data will be used in concert with geotechnical data (Section 4.4) to support engineering design evaluations of structures during 30% RD. Methods to address the structures data gaps are described in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b).

4.5.2 Sediment Thickness over Armored Banks

For armored banks, potential remedial actions will need to be designed while considering the location of the armor toe and the thickness of sediment above the armor layer. Sediment thickness above engineered armor is a Phase II data gap. Methods to address this data gap and the specific locations for data collection are described in the Phase II QAPP Addendum.

4.5.3 Debris

In areas with RAL exceedances, large surface debris may need to be removed and disposed of during remedial construction. The photographic documentation conducted during the Phase I bank visual inspection provides useful information regarding the general locations of shoreline debris above MLLW (Appendix A). Specific location data (i.e., horizontal coordinates) for large debris above MLLW will be collected during the topographic survey to be conducted during the Phase II PDI. The forthcoming addendum to the Survey QAPP will identify methods for collecting visible debris location data.

Identification of large surface debris below MLLW is not considered a data gap for the Phase II PDI. Multibeam bathymetric data collected during the Phase I PDI (Section 2.4) will be used to identify and locate any large surface debris for 30% RD in areas where remedial action will occur.

4.5.4 Vegetation

As part of the bank visual inspection conducted in Phase I (Section 2.2), information was collected regarding the presence of vegetation along the shoreline. More detailed vegetation or habitat information may be needed once the extent of banks requiring remedial action (including disturbance of vegetation) is more clearly understood (i.e., during 30% RD). Methods for detailed, location-specific vegetation or habitat assessments may be identified as a Phase III data need during 30% RD.

4.5.5 Waste Characterization for Disposal

Disposal facilities typically require waste characterization data to compare their facility permit standards with the waste profile (i.e., bulk chemistry) of sediment to be disposed of at the facility. Waste characterization for materials to be dredged is considered a data gap.

Waste characterization will be performed after 30% RD to provide contaminant concentrations representative of those in waste material. The characterization may be based on mathematical compositing of Phase II core results, or on composite samples created from Phase II archive samples collected within dredge areas. This characterization must be conducted after 30% RD—which will occur after dredging depths have been determined—in order to identify the representative characteristics of the material from the design dredge prisms.

5 Next Steps

The data gaps identified in this document will be addressed through the Phase II PDI. Specific details regarding data collection—including chemistry, geotechnical, and other engineering information—are described in the Phase II QAPP Addendum (Anchor QEA and Windward 2023b) or in the addendum to the Survey QAPP. After these addenda are approved by EPA, LDWG will conduct the Phase II PDI. The design dataset will be supplemented with the Phase II data and used in 30% RD.

Phase II PDI data collection is planned for spring 2024. The 30% RD is anticipated to begin in late 2024 as the Phase II PDI data become available. The need for a Phase III PDI will be determined after LDWG receives EPA's comments on 30% RD. If needed, this phase is anticipated to take place between October 2025 and January 2026, per the project schedule, and the results incorporated into 90% RD.

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Appendix A
Bank Visual Inspection Observations and Photographs

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Appendix B
Structures Visual Inspection Forms

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Appendix C
PDI Bathymetric Survey Data Report

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Appendix D
Data Management Rules

Appendix E
Recommended Recovery Category Modifications

Appendix F
Interpolation Methods for Delineating Areas with RAL Exceedances

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Appendix G
Preliminary Technology Assignment Options for Areas with RAL Exceedances

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Appendix H
cPAH RAL Exceedance Areas Relative to 2014 ROD RALs

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Appendix I
Middle Reach Design Dataset Including PDI Phase I Data