100% Remedial Design Basis of Design Report

Appendix A
Pre-Design Investigation Phase III Data Report for the Lower Duwamish Waterway Upper Reach

Lower Duwamish Waterway Group

City of Seattle / King County / The Boeing Company

100% Remedial Design Basis of Design Report

Appendix A – Pre-Design Investigation Phase III Data Report for the Lower Duwamish Waterway

For submittal to

US Environmental Protection Agency
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ABBREVIATIONS

ARL	Analytical Resources, LLC
BBP	butyl benzyl phthalate
BODR	Basis of Design Report
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
DER	Data Evaluation Report
DQO	data quality objective
EPA	US Environmental Protection Agency
ESD	explanation of significant differences
FNC	federal navigation channel
FS	Feasibility Study
GPS	global positioning system
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
IDW	inverse distance weighting
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LPAH	low-molecular-weight polycyclic aromatic hydrocarbons
MLLW	mean lower low water
OC	organic carbon
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PDI	Pre-Design Investigation
QAPP	Quality Assurance Project Plan
RAA	remedial action area
RAL	remedial action level
RAO	remedial action objective
RD	remedial design
RI	Remedial Investigation
RM	river mile
ROD	Record of Decision
SDG	sample delivery group
SVOC	semivolatile organic compound
TEQ	toxic equivalent
TOC	total organic carbon
USACE	US Army Corps of Engineers

1 Introduction

This document presents the results of Phase III Pre-Design Investigation (PDI) conducted per the fourth amendment to the Administrative Order on Consent in support of remedial design (RD) for the upper reach (river mile [RM] 3.0 to RM 5.0) of the Lower Duwamish Waterway (LDW) Superfund site in King County, Washington (Map 1-1). The Phase III results are presented herein separately and in combination with the design dataset, which includes results from all three phases of the PDI as well as pre-PDI data from the Remedial Investigation/Feasibility Study (RI/FS) and post-FS sampling events. The PDI has been implemented in accordance with the US Environmental Protection Agency (EPA)-approved PDI Quality Assurance Project Plan (QAPP) (Windward and Anchor QEA 2020) and the Addenda to the PDI QAPP for Phase II (Phase II QAPP Addendum) (Anchor QEA and Windward 2021) and Phase III (Phase III QAPP Addendum) (Windward and Anchor QEA 2022).

A Phase III data package was developed and provided to EPA; it can be accessed on https://ldwg.org. This data package included maps and coordinates of sediment sampling locations, field notes and forms, chain of custody forms, laboratory and validation reports, photographs, and validated analytical results.

1.1 Data Quality Objectives

Phase III sediment sampling and topographical surveying was conducted to address data gaps remaining after Phase I and II activities. Phase I and II results are presented in the PDI Data Evaluation Report (DER) (Anchor QEA and Windward 2022). With the completion of Phase III, all 14 data quality objectives (DQOs) outlined in the PDI QAPP (Windward and Anchor QEA 2020) have now been fully met. Phase III data collection defined in the Phase III PDI QAPP and survey QAPP addenda (Windward and Anchor QEA 2022) satisfied the remaining elements of DQOs 10, 11, and 12 (Table A1-1).

Table A1-1
DQOs for Phases I and II PDI in the Upper Reach

DQO	DQO Description	Activities Conducted to Address DQO
DQO1	Delineate 0–10-cm RAL exceedances in Recovery Category 2/3.	DQO was met through the collection and chemical analysis of surface sediment (0–10-cm) samples in Phases I, II, and III.
DQO2	Delineate 0–10-cm RAL exceedances in Recovery Category 1.	
DQO3	Delineate 0–45-cm intertidal RAL exceedances in Recovery Category 2/3.	DQO was met through the collection and chemical analysis of subsurface intertidal sediment (0–45-cm) samples in Phases I, II, and III.
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.	DQO was met through the collection and chemical analysis of subsurface subtidal sediment (0–60-cm) samples in Phases I, II, and III.
DQO6	Delineate 0–60-cm RAL exceedances in Recovery Category 1.	
DQO7	Delineate RAL exceedances in shoaling areas.	DQO was met through the collection and chemical analysis of shoaling interval samples in Phases I, II, and III
DQO8	Conduct a visual inspection of the banks in the upper 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.	DQO was met through the visual bank inspection conducted throughout the upper reach in Phase I.
DQO9	If feasible, delineate RAL exceedances in areas under overwater structures.	DQO was met through Phase I and Phase II sampling, confirming that contamination does not extend under any overwater structures in the upper reach, with the exception of the South Park Bridge.
DQO10	Further delineate RAL exceedances, as needed for unbounded areas.	DQO was met through further delineation of RAL exceedance areas in Phases II and III.
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.	DQO was met through sampling and surveying of banks during Phases II and III.
DQO12	Delineate vertical elevation of RAL exceedances in dredge (and partial dredge and cap) areas and collect subsurface sediment chemistry data in cap areas where contamination under caps will remain.	DQO was met through analysis of vertical extent samples in Phases II and III.
DQO13	Collect geotechnical data as needed depending on technology proposed and/or physical characteristics of RAL exceedance areas.	DQO was met through geotechnical investigations in Phase II.

DQO	DQO Description	Activities Conducted to Address DQO
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).	DQO was met through the following efforts during Phases I and II PDI: • Inspecting structures and outfalls in Phase II near Phase I RAL exceedance areas • Measuring the thickness of sediment on top of armored banks to estimate the volume of sediment over armoring and identify the toe of armored slopes (where applicable) in Phase II • Assessing extent of vegetation along banks to inform engineering design • Archiving samples for waste characterization to inform disposal options for engineering design

Notes:
DQO: data quality objective
PCB: polychlorinated biphenyl
PDI: pre-design investigation
RAL: remedial action level

1.2 Report Organization

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

- Section 2: Phase III PDI Summary
- Section 3: Data Evaluation
- Section 4: Next Steps
- Section 5: References

The following attachments are appended to this document:

- Attachment A.1: Mudline Elevations and Coordinates
- Attachment A.2: Topographic Survey Data Report and Bank Features
- Attachment A.3: Vertical core diagrams with concentrations
- Attachment A.4: Interpolation Methods for Delineating Areas with Remedial Action Level (RAL) Exceedances

2 Phase III Pre-Design Investigation Summary

This section presents the results from the LDW upper reach Phase III PDI sediment sampling and analysis, topographical surveying, and inadvertent discovery plan implementation. Section 3 identifies areas with RAL exceedances based on the design dataset, including Phase III results.

2.1 Sediment Sampling

2.1.1 Field Sampling Overview

During the Phase III sampling in December 2022, sediment samples were collected from 77 locations throughout the upper reach of the LDW. [1] Specifically, surface sediment grab samples were collected from 19 locations, and subsurface sediment cores (including short cores [i.e., 0–45-cm or 0–60-cm cores]; shoaling cores; and deeper vertical extent cores) were collected from 62 locations (Maps A-2a, A-2b, and A-3); some surface and subsurface samples were collected at the same locations.

Target and actual sampling coordinates and mudline elevations for the sampling locations (both surface and subsurface) are provided in Attachment A.1. Maps of target vs. actual sampling locations are available in the Phase III data package.

2.1.1.1 Field Methods

Surface grab samples and subsurface sediment cores were collected and processed following the standard operating procedures described in Appendix F of the QAPP and Appendix J of the Phase II QAPP Addendum (Windward and Anchor QEA 2020; Anchor QEA and Windward 2021). Generally, sediment samples were collected from target depths using a pneumatic grab sampler (for surface sediment) or a vibracorer (for subsurface cores and deeper vertical cores). In several cases, samples were collected by hand during a low tide.

Mudline elevations were recorded for all locations. For surface sediment samples, mudline elevations were estimated using global positioning system (GPS) coordinates and bathymetry survey data. For subsurface sediment samples, mudline elevations were necessary for sample processing, so they were calculated in the field using field-measured tidal stage and water depth information (referred to as the real time kinematic tide elevation). For the subsurface sediment sampling locations, a table comparing real time kinematic and bathymetry mudline elevations is presented in Attachment A.1.

2.1.1.2 Field Deviations

Deviations from the Phase III QAPP Addendum (Windward and Anchor QEA 2022) involved modifications to sediment core acceptance criteria at six locations and the inability to collect

[1] One additional surface sediment sample was collected in March 2023. This sample is included in the counts presented herein and has been incorporated into the revised RAL exceedance areas.

acceptable cores at two locations. EPA was notified of all modifications when the samples were collected.

Details regarding the six locations with core acceptance criteria deviations for Phase III are described below. These field deviations did not affect data quality (i.e., the deviations were minor); thus samples from these cores were analyzed in accordance with the QAPP.

- **Location 757** – After three attempts, the core from the second attempt was accepted (with 71.1% recovery, below the target recovery criteria of 75%), because it had the highest recovery and met the target penetration of 8 ft.
- **Location 767** – After three attempts, the core from the first attempt was accepted (with 6.5 ft of penetration, less than the target penetration depth of 8 ft), because all three attempts met early refusal. The accepted core had the deepest penetration (6.5 ft) and highest recovery (100%).
- **Location 787** – After two attempts, the core with 72.1% recovery (below the target recovery criteria of 75%) that met the -26-ft mean lower low water (MLLW) target elevation was accepted, because the top 4–5 ft comprised soft, unconsolidated sediment, which prevented better recovery.
- **Location 799** – After three attempts that did not meet the target recovery criteria, the core from the second attempt was accepted, because it met the 6.5-ft target drive depth and had the highest recovery (71.1%).
- **Location 806** – After three attempts that did not meet the target recovery criteria, the core from the second attempt was accepted, because it met the 6.5-ft target drive depth and had the highest recovery (66.7%).
- **Location 814** – A 6.5-ft target drive depth could not be achieved because of early refusal. After seven unsuccessful attempts, a core from the final attempt was accepted because it had the deepest penetration (4.5 ft) and highest recovery (80.0%).

Details regarding the two locations where attempts to collect a core resulted in samples that did not meet the target criteria are described below. Unlike the six locations described above (for which deviations were minor), samples from these two locations were determined to be unsuitable for the objectives described in the QAPP for these locations. Thus, samples from the following locations were not analyzed.

- **Location 763** – A core that met the target elevation (-30 ft MLLW) could not be collected. After three unsuccessful attempts that hit refusal at approximately -21 ft MLLW, a core from the fourth attempt that hit refusal at -26 ft MLLW was archived. The samples from this core were not analyzed because they did not meet the objectives for this location described in the QAPP.
- **Location 807** – A 0–45-cm subsurface sediment sample could not be collected. After three unsuccessful attempts that hit early refusal, the core from the second attempt was archived,

because it had the deepest (1.0 ft) and highest (100%) recovery. This 0–45-cm sample was not analyzed because it did not meet the objectives for this location described in the QAPP. Instead, as indicated in the QAPP, the archived 0–45-cm sample from location 632 (Phase II) was analyzed.

2.1.1.3 Counts of Samples Collected and Analyzed

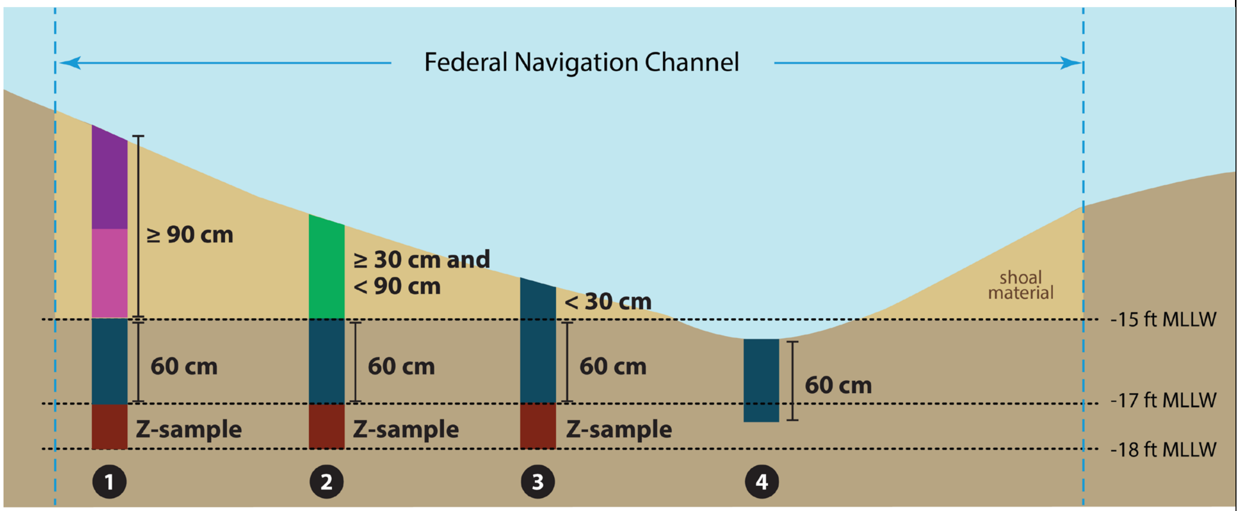
The numbers of sampling locations in the Phase III PDI sampling effort are presented in Table A2-1. Overall, sediment was collected from a total of 77 locations during the Phase III PDI sampling effort (Maps A-2a and A-2b). The sediment depth intervals collected at each location were specified in the Phase III QAPP Addendum (Windward and Anchor QEA 2022), based on the bathymetry of the sample location (intertidal, subtidal, or shoaling area) and the recovery category, consistent with Record of Decision (ROD) Table 28 (EPA 2014). Targeted depth intervals in the federal navigation channel (FNC) shoaling areas are shown in Figure A.2-1; Map A-3 shows the intervals sampled at each shoaling location during the PDI.

Table A2-1
Summary of Upper Reach Locations Sampled for Chemical Analysis During the PDI

Phase	Total Locations[1]	No. of Surface Sediment Locations (0–10 cm)	No. of Subsurface Sediment Locations		No. of Shoal Core Locations	Vertical Extent Core Locations
			Intertidal (0–45 cm)	Subtidal[2] (0–60 cm)		
Phase I (Summer 2020)	266	249	120	88[3]	39[3]	0
Phase II (Summer 2021)	208	82	87	83[4]	10[4]	86
Phase III (Winter 2022)	77	19[5]	21[6]	34	7	45[6]
Total	**551**	**350**	**228**	**205**	**56**	**131**

Notes:
1. The total locations count is less than the sum of the counts by location type because some locations have results for multiple intervals (e.g., surface and subsurface samples are co-located).
2. The number of 0–60-cm locations does not include shoal core locations.
3. No shoal material was present at one Phase I location (217) proposed for the collection of shoaling intervals. Instead, this location is counted as a 0–60-cm subtidal subsurface location (i.e., rather than a shoaling location, as proposed in the QAPP) (Windward and Anchor QEA 2020).
4. No shoal material was present at two Phase II locations (548 and 549) proposed for the collection of shoaling intervals. Instead, these locations are counted as 0–60-cm subtidal subsurface locations (i.e., rather than shoaling locations, as proposed in the Phase II QAPP Addendum) (Anchor QEA and Windward 2021).
5. The Phase III counts also include one surface sediment sample (SS826) collected in March 2023.
6. As described in Section 2.1.1.2, one intertidal (0–45-cm) core (Location 807) and one vertical extent core (Location 763) did not meet the target criteria; samples from these locations were not analyzed.
QAPP: Quality Assurance Project Plan
PDI: Pre-Design Investigation

Figure A.2-1
Federal Navigation Channel Design Sampling



1. When thickness of shoal material is greater than or equal to 90 cm, then the core will be taken to -18 ft MLLW and three samples will be collected. Two samples will represent the shoal material and will be archived (Tier 2) and one sample will represent material between -15 ft and -17 ft MLLW and will be analyzed (Tier 1). A 1 ft Z-sample (-17 ft to -18 ft MLLW) will be collected and archived. A 0-10 cm sample will also be collected (not shown).

2. When thickness of shoal material is greater than or equal to 30 cm and less than 90 cm, then the core will be taken to -18 ft MLLW and two samples will be collected. One sample will represent the shoal material and will be Tier 2 and the other sample will represent material between -15 ft and -17 ft MLLW and will be Tier 1. A 1 ft Z-sample (-17 ft to -18 ft MLLW) will be collected and archived. A 0-10 cm sample will also be collected (not shown).

3. When thickness of shoal material is less than 30 cm, then the core will be taken to -18 ft MLLW and one sample will represent both the shoal material and the material between -15 ft and -17 ft MLLW. A 1 ft Z-sample (-17 ft to -18 ft MLLW) will be collected and archived. A 0-10 cm sample will also be collected (not shown).

4. In the portions of the FNC that are not shoaled (deeper than -15 ft MLLW) a 0-60 cm sample will be collected. A 0-10 cm sample will also be collected (not shown).

Note: The shoal thickness will be measured in the field based on field bathymetry at each location. The shoal thickness values provided here are approximate.

The numbers of samples collected and analyzed for Phase III are presented in Table A2-2. Field duplicates are not included in the sample counts. For many locations, multiple samples were collected, so the location counts and sample counts do not match. In the shoaling areas within the FNC, cores were collected to characterize the shoal material above the authorized navigation depth of -15 ft MLLW in this reach of the LDW, as well as the 60-cm interval below the authorized depth (the allowable overdredge interval between -15 and -17 ft MLLW) and Z-samples below the overdredge interval (Figure A2-1; Map A-3). In addition, vertical extent cores (including the appropriate subsurface RAL interval, where needed) were collected for further vertical delineation.

Table A2-2
Summary of Upper Reach Samples Collected and Analyzed for at Least One Analyte During the Phase III PDI

Phase	Category	No. of Samples[1]				
		RAL Interval Samples				Samples Below RAL Interval (Z-Layer and Vertical Extent)
		Surface Sediment (0–10 cm)	Subsurface Sediment		Shoal Intervals[3]	
			Intertidal (0–45 cm)	Subtidal (0–60 cm)[2]		
Phases I and II[4]	Archive samples analyzed as part of Phase III[5]	0	3	0	1	8
Phase III[6]	Total collected	19	21	34	19	420
	Total analyzed[5]	19	16	20	19	344
	Total archived	0	5	14	0	76

Notes:
1. Field duplicates are not included in counts.
2. The number of 0–60-cm samples does not include shoal core samples.
3. Sample depths and number of samples collected per location for subsurface samples in shoaling areas varied depending on the depth of the shoal at each location (see QAPP Figure 4-1) (Windward and Anchor QEA 2020). Shoal interval samples counted herein include shoal material (i.e., sediment above -15 ft MLLW) and sediment from the -15- to -17-ft interval. Details for each shoaling location are presented on Map A-3.
4. Counts in this row enumerate Phase II samples that were analyzed as part of Phase III.
5. Total analyzed is the count of samples submitted for analysis through April 2023.
6. Counts in these rows include only samples collected during Phase III.
MLLW: mean lower low water
PDI: Pre-Design Investigation
QAPP: Quality Assurance Project Plan
RAL: remedial action level

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 described briefly in this section and in detail in the QAPP (Windward and Anchor QEA 2020) and Phase III QAPP Addendum (Windward and Anchor QEA 2022). This section also discusses laboratory deviations from the QAPP. Laboratory and validation reports and the full chemistry results are provided in the PDI data packages.[2]

Analytical Resources, LLC (ARL) performed polychlorinated biphenyl (PCB) Aroclor, carcinogenic polycyclic aromatic hydrocarbon (cPAH), semivolatile organic compound (SVOC), dioxin/furan, arsenic and other metals including mercury, total organic carbon (TOC), and total solids analyses. Sediment samples were analyzed according to the methods presented in Table A2-3.

[2] Data packaged can be accessed on https://ldwg.org.

Table A2-3
Analytical Methods for Sediment Analyses

Analyte	Method	Reference	Extraction Solvent	Laboratory
PCB Aroclors	Gas chromatography/ electron capture detector	EPA 3546/EPA 8082A	Hexane/acetone	ARL
PAHs/SVOCs	Gas chromatography/mass spectrometry	EPA 3546/EPA 8270E/EPA 8270E-select ion monitoring	Dichloromethane/ acetone	ARL
cPAHs/SVOCs	Gas chromatography/mass spectrometry	EPA 3546/EPA 8270E-select ion monitoring	Dichloromethane/ acetone	ARL
Dioxins/furans	High-resolution gas chromatography/high-resolution mass spectrometry	EPA 1613B	Toluene	ARL
Metals	Inductively coupled plasma-mass spectrometry	EPA 3050B EPA 6020B Universal cell technology-kinetic energy discrimination	NA	ARL
Mercury	Cold vapor-atomic fluorescence spectrometry	EPA 7471B	NA	ARL
TOC	High-temperature combustion	EPA 9060A	NA	ARL
Total solids	Drying oven	Standard Method 2540G	NA	ARL

Notes:
ARL: Analytical Resources, LLC
cPAH: carcinogenic polycyclic aromatic hydrocarbon
EPA: US Environmental Protection Agency
NA: not applicable
PAH: polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
SVOC: semivolatile organic compound
TOC: total organic carbon

A summary of the total numbers of samples analyzed for each contaminant of concern (COC) in Phase III is presented in Table A2-4. Field duplicate samples are not included in the sample counts.

Table A2-4
Total Number of Chemical Analyses in Phase III samples

Sediment Type	Depth Interval	Total Samples Analyzed	No. of Samples Analyzed[1]								
			Human Health Risk Drivers				Other Benthic Risk Drivers[2]				TOC/Total Solids
			PCB Aroclors	Dioxins/ Furans	Arsenic	cPAHs	Other Metals	PAHs	Phthalates	Other SVOCs	
Surface	0–10 cm	19	17	0	0	3	2	3	1	6	17
Subsurface	Intertidal (0–45 cm)	19	19	6	0	0	0	0	0	0	19
Subsurface	Subtidal (0–60 cm)	20	20	0	0	0	0	0	1	0	20
Shoal intervals (depth varies)[3]		20	20	0	3	4	4	4	0	0	20
Vertical extent (depth varies)		352	350	18	31	14	14	14	19	0	352

Notes:
1. Sample counts include PDI samples submitted for analysis through April 2023 and do not include field duplicates. Counts for Phase III include Phase II samples analyzed as part of Phase III.
2. 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 (bis[2-ethylhexyl]phthalate, 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, hexachlorobenzene, n-nitrosodiphenylamine, pentachlorophenol, and phenol) are counted if at least one of the analytes in the group was analyzed.
3. Shoaling interval samples consisted of shoaled material from the FNC (i.e., sediment above -15 ft MLLW in this reach of the LDW) and sediment from the -15 to -17-ft interval.

BBP: butyl benzyl phthalate
COC: contaminant of concern
cPAH: carcinogenic polycyclic aromatic hydrocarbon
FNC: Federal Navigation Channel
HPAH: high-molecular-weight polycyclic aromatic hydrocarbons
LDW: Lower Duwamish Waterway
LPAH: low-molecular-weight polycyclic aromatic hydrocarbons
MLLW: mean lower low water
PAH: polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
PDI: Pre-Design Investigation
RAL: remedial action level
RAO: remedial action objective
SVOC: semivolatile organic compound
TOC: total organic carbon

2.1.2.2 Analytical Laboratory Deviations from the QAPP

There was one deviation from the methods and procedures described in the QAPP (Windward and Anchor QEA 2020) that occurred in the analytical laboratory. Samples from Phase II locations IT632, IT699, IT814, and SC767 were identified for analysis during Phase III (sample delivery group [SDG] 22L0473). The samples were qualified due to hold time exceedances for PCBs, dioxins/furans, TOC, and total solids. Because PCBs and dioxins/furans are persistent and stable, and because samples were stored frozen, the data were determined to be acceptable for use as qualified by the validator.

2.1.2.3 Data Validation Results

EcoChem performed independent data validation on all analytical chemistry results. 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 2020). Stage 2B validation review was conducted on the remaining datasets.

The data validation reports, which are included in the data packages, comprise 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 for Phase III.

- Replicate relative percent difference outside of quality control limits for EPA 7471 mercury (3 of 3 SDGs), individual EPA 1613 dioxins/furans (2 of 4 SDGs), EPA 9060 TOC (3 of 11 SDGs), and individual EPA 8082A PCB Aroclors (1 of 11 SDGs).
- Matrix spike percent recoveries outside of quality control limits for EPA 8270E SIM SVOC compounds (2 of 3 SDGs), EPA 9060 TOC (2 of 11 SDGs), and individual EPA 8082A PCB Aroclors (1 of 11 SDGs).

All data presented in this report were determined to be acceptable for use as qualified.

2.1.2.4 Sediment Chemistry Results

Sediment data in the Phase III PDI dataset were compared with RALs presented in ROD Table 28 (EPA 2014), and cPAH results were compared with RALs presented in the cPAH explanation of significant differences (ESD) (EPA 2021),[3] in order to delineate RAL exceedance areas. A summary of RAL exceedances in the Phase III PDI dataset is presented in Table A2-5, and these exceedances (along with all exceedances in the design dataset) are shown by location on Maps A-4a through A-4j. A discussion of the full design dataset is presented in Section 3.2.

[3] cPAH results are compared to the 2014 ROD RALs in Appendix F of the Basis of Design Report (BODR).

Table A2-5
Summary of RAL Exceedances in the Phase III PDI Dataset

COC	Counts by Interval in the Phase III PDI Dataset[1]							
	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	%
Human Health COCs								
PCBs	1/17	6	6/19	32	6/20	30	1/20	5
Dioxin/furan TEQ	NA	-	1/6	17	NA	-	NA	-
Arsenic	NA	-	na	-	NA	-	0/3	0
cPAHs[3]	0/3	0	na	-	NA	-	0/4	0
Benthic COCs (with RAL Exceedances)[4]								
BBP	NA	-	na	-	1/1	100	NA	-
PAHs[5]	0/1	0	na	-	na	-	1/4	25

Notes:
1. Sample counts include PDI samples submitted for analysis through April 2023 and do not include field duplicates. Counts for Phase III include Phase II samples analyzed as part of Phase III.
2. Shoal interval samples consisted of shoaled material from the FNC (i.e., sediment above -15 ft MLLW in this reach of the LDW) and sediment from the -15 to -17-ft interval (see Map A-3).
3. cPAH results are compared with the RALs presented in the cPAH ESD (EPA 2021).
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 Phase III PDI dataset.
5. PAHs with exceedances of benthic RALs include fluoranthene, phenanthrene, total HPAHs, and total LPAHs.
BBP: butyl benzyl 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
LDW: Lower Duwamish Waterway
LPAH: low-molecular-weight polycyclic aromatic hydrocarbon
MLLW: mean lower low water
NA: not applicable (no Phase III samples analyzed)
PAH: polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
PDI: Pre-Design Investigation
RAL: remedial action level
TEQ: toxic equivalent

2.2 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 G of the Phase II QAPP Addendum (Anchor QEA and Windward 2021), described the locations where archaeological monitoring was required and provided direction, contact information, and procedures to follow should an inadvertent discovery occur.

Prior to implementation of the field program, Stell Environmental Enterprises conducted a literature review of the Washington Information System for Architectural and Archaeological Records Data, as well as other cultural and environmental documents. During this review, 11 cultural resource surveys, 7 archaeological sites, 5 cemeteries, 6 registered historic properties, and 3,083 structures were identified within 1 mile of the upper reach.

During the Phase III PDI, Stell Environmental Enterprises performed archaeological monitoring from December 5 to 13, 2022. No significant cultural resources were encountered during monitoring.

2.3 Topographic Surveys

Topographic surveying was used to gather data to address DQO11 (Table A1-1), following the methods outlined in the Survey QAPP Addendum (Anchor QEA and Windward 2022b). The areas where topographic surveying was performed are shown on Map A-5. The topographic survey began on October 5, 2022, and was completed on October 7, 2022. The equipment and methods used to perform this survey were selected to obtain data with precision and accuracy comparable to those of the data from the bathymetric surveys. The key targets and related data for the topographic surveys are summarized in Table A2-6. The report from True North Land Surveying's 2022 topographic survey is provided in Attachment A.2.

Table A2-6
Key Targets and Related Datums for Topographic Surveying Description

Description	Quantity or Datum
GPS horizontal positioning accuracy	+/- 0.3 ft minimum
Total location horizontal survey accuracy	+/- 0.1 ft minimum
Horizontal datum	North American Datum of 1983/1991 Washington North Zone
GPS vertical survey accuracy	+/- 0.2 ft minimum
Total location vertical survey accuracy	+/- 0.02 ft minimum
Vertical datum	MLLW

Notes:
Source: Table 3 of the Survey QAPP (Anchor and Windward 2019).
GPS: global positioning system
MLLW: mean lower low water
QAPP: Quality Assurance Project Plan

2.3.1 Field Deviations and Adjustments

Locations of the Area 33/34 outfalls (at RM 4.9) were not surveyed because permissions or right-of-entry agreements were not available. This did not result in an adverse effect on data needed for RD.

3 Data Evaluation

This section presents an updated count of RAL exceedances in the design dataset, as well as the RAL exceedance areas based on the design dataset. The data management rules for the design dataset are presented in the PDI DER (Anchor QEA and Windward 2022). The design dataset includes the PDI data as well as the pre-PDI data from the RI/FS and post-FS sampling events (Table A3-1).

Table A3-1
Number of Upper Reach Design Dataset Locations with RAL Intervals by Data Source

Dataset	Date Range	No. of Surface Sediment Locations[1] (0–10 cm)	Subsurface Sediment Locations[1]		No. of Shoal Core Locations[1]
			No. of Intertidal (0–45 cm)	No. of Subtidal (0–60 cm)	
RI/FS	1990–2010	353	0	14	0
Post-FS	2010–2019	229	0	0	4[1]
PDI (Phase I)[3]	2020	178	92	71	29[4]
PDI (Phase II)[3]	2021	80	54	63	13[5]
PDI (Phase III)[3]	2022	19	19	20	8[6]
Total		**859**	**165**	**168**	**54**

Notes:
1. When a sample location is re-occupied, the sample count includes only the new sample if the new sample has the same chemical list as (or one longer than) the older sample. However, if the new sample has a shorter chemical list than the older sample, both samples are included in the count.
2. The four post-FS shoal locations include a total of eight discrete depth interval samples. Three of these cores were collected in 2012 as part of the USACE sampling effort, and one core was collected in 2016 as part of sampling done at South Park Marina.
3. PDI location counts presented here are not intended to match those in Section 2. This table presents counts of locations where various RAL intervals were analyzed; Table A2-1 presents counts of locations where samples were collected (i.e., not necessarily analyzed), and Table A2-2 presents sample counts, which may be greater than the values presented here because, in some cases, there are multiple samples per location.
4. PDI Phase I shoal locations have a total of 52 discreet depth interval samples included in the design dataset.
5. PDI Phase II shoal locations have a total of 26 discreet depth interval samples included in the design dataset.
6. PDI Phase III shoal locations have a total of 20 discreet depth interval samples included in the design dataset.
PDI: Pre-Design Investigation
RAL: remedial action level
RI/FS: Remedial Investigation/Feasibility Study
USACE: US Army Corps of Engineers

3.1 Comparison of Design Dataset with RALs

A summary of RAL exceedances in the design dataset is presented in Table A3-2 and shown by location on Maps A-4a through A-4j.

Table A3-2
Summary of RAL Exceedances in the 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	66/776	9	24/158	15	45/165	27	1/106	1	136/1,205	11
Dioxin/furan TEQ	3/137	2	6/56	11	0/9	0	0/13	0	9/215	4
Arsenic	8/570	1	1/94	1	0/38	0	0/33	0	9/735	1
cPAHs[3]	1/510	0.2	0/61	0	0/36	0	0/31	0	1/638	0.2
Benthic COCs (with RAL Exceedances)[4]										
Lead	1/563	0.2	0/9	0	0/32	0	0/31	0	1/635	0.2
Mercury	3/568	0.5	0/9	0	0/37	0	1/35	3	4/649	0.6
Zinc	1/532	0.2	0/9	0	0/35	0	0/31	0	1/607	0.2
PAHs	3/517	0.6	1/10	10	0/37	0	2/31	6	6/595	1
Benzoic acid	2/466	0.4	0/9	0	0/30	0	0/26	0	2/531	0.4
Phenol	1/472	0.2	0/9	0	0/30	0	0/26	0	1/537	0.2
BBP	9/475	2	0/9	0	2/42	5	0/26	0	11/552	2

Notes:
1. The design dataset includes samples from the pre-PDI and PDI datasets. Sample counts include PDI samples submitted for analysis through April 2023.
2. Shoal interval samples consisted of shoaled material from the FNC (i.e., sediment above -15 ft MLLW in this reach of the LDW) and sediment from the -15 to -17-ft interval (see Map A-3). In many cases, this count includes multiple samples per location.
3. cPAH results are compared with the RALs presented in the cPAH ESD (EPA 2021). See BODR Appendix F for a comparison of cPAH results with the 2014 ROD RALs.
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.
BBP: butyl benzyl phthalate
BODR: Basis of Design Report
COC: contaminant of concern
cPAH: carcinogenic polycyclic aromatic hydrocarbon
ESD: explanation of significant differences
FNC: Federal Navigation Channel
LDW: Lower Duwamish Waterway
MLLW: mean lower low water
PAH: polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
PDI: Pre-Design Investigation
RAL: remedial action level
ROD: Record of Decision
TEQ: toxic equivalent

Key takeaways from Table A3-2 include the following:

- **PCBs** – PCBs were the primary COC in the upper reach with the most RAL exceedances. Concentrations of PCBs were greater than the RAL in 11% 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 the following (listed in order of frequency of RAL exceedances): butyl benzyl phthalate (BBP), dioxins/furans, arsenic, polycyclic aromatic hydrocarbons (PAHs), mercury, benzoic acid, cPAHs, lead, zinc, and phenol. These COCs exceeded the RAL in 0.2% to 4% of the design dataset samples. No PDI locations had cPAH toxic equivalents (TEQs) greater than the RALs in the EPA ESD (EPA 2021); one pre-PDI surface sediment sample had a concentration exceeding the ESD RAL at a location where other PAHs and BBP also exceeded their respective RALs.
- **Surface samples** – The majority of surface RAL exceedances were for PCBs; there were PCB RAL exceedances in 9% of surface sediment samples in the design dataset. Other COCs exceeded the RAL in surface sediment in up to 2% of the design dataset.
- **Subsurface samples** – The majority of subsurface RAL exceedances were for PCBs; there were PCB RAL exceedances in 21% of the subsurface samples (both intertidal and subtidal areas, not including shoaling cores). Dioxins/furans exceeded the RAL in 9% of subsurface samples (all exceedances in intertidal areas). Other COCs exceeded the subsurface RALs in up to 4% of the design dataset. Other COCs with concentrations greater than subsurface RALs were arsenic (one intertidal subsurface sample), PAHs (one intertidal subsurface sample), and BBP (two subtidal subsurface sample).
- **Shoaling samples** – There were no RAL exceedances in the majority of the shoaling samples. The exceptions were one sample each for PCBs (one sample), mercury (one sample), and PAHs (one sample). In addition, there were some Z-sample and vertical extent sample results from shoaling locations in the FNC at depth intervals below where ROD RALs apply (i.e., below -17 ft MLLW in this reach of LDW) with concentrations greater than shoaling RALs; these samples are shown in purple on Map A-3.

Vertical core diagrams for all cores (i.e., not just shoaling cores) are presented on the Map A-4 series; vertical extent samples with exceedances of surface sediment RALs are shown in purple. In addition, vertical core diagrams with concentrations are included in Attachment A.3 for all PDI samples. These data provide vertical extent of contamination information to be used in 90% RD within RAL exceedance areas.

3.2 Areas with RAL Exceedances

This section presents a summary of the updated data interpolation process used to identify areas with RAL exceedances in the upper reach. Three phases of interpolation have been performed as new information has been obtained during three successive PDIs: Phase I, Phase II, and Phase III investigations. The updated interpolation results presented herein are supported by the full design dataset, which incorporates Phase III data as well as data from all prior investigations. Details of the updated data interpolation are presented in Attachment A.4.

3.2.1 Defining Areas with RAL Exceedances

Spatial data interpolation methods were used to delineate areas with RAL exceedances for 90% RD. RAL interval data from the design dataset were used in the data interpolations. 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). Interpolation method selection and application were developed through a series of technical meetings with Lower Duwamish Waterway Group (LDWG) and EPA statisticians. The PDI DER (Anchor QEA and Windward 2022) and Appendix K to that document provide a summary of the interpolation analyses and results, based on data available at that time. This section summarizes any updates that have occurred with the incorporation of Phase III data into the design dataset.

A detailed geostatistical evaluation of the design dataset, including Phase III data, is presented in Attachment A.4. Specifically, Attachment A.4 provides the following information: updated indicator kriging semivariograms for PCBs; comparisons of isotropic and anisotropic indicator kriging methods; Phase III indicator kriging interpolation maps for PCBs in surface, subsurface, and combined surface and subsurface sediment; comparisons of Phase II and Phase III PCB interpolations (i.e., before and after the addition of Phase III data); and updated Thiessen polygons for COCs other than PCBs.

3.2.1.1 Interpolation Methods

Consistent with previous interpolation work in the upper reach (Anchor QEA and Windward 2022, Appendix K), PCBs were selected as the primary COC for detailed numerical data interpolation, because PCBs delineate a large majority[4] of the RAL exceedance areas in the upper reach. PCBs were interpolated using indicator kriging to delineate PCB RAL exceedance area boundaries.

PCB indicator kriging 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.[5] Using a

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[4] Based on the results of the interpolation work described in this section, PCBs were estimated to account for the majority 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 or square ft) to the total RAL exceedance area circumscribed by all COCs (see Map K-4a of the Phase II DER (Anchor QEA and Windward 2022)).

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

GIS raster computation, the interpolations of surface and subsurface sediment were merged into a single map showing the combined PCB exceedance footprint of both surface and subsurface layers.

RAL exceedance area boundaries were expanded in localized areas where other COCs exceeded RALs but PCBs did not. Because these areas were small and localized, the RAL exceedance area boundaries for COCs other than PCBs were established using Thiessen polygons. Other COCs that determined the local RAL exceedance area boundary included metals, PAHs, other SVOCs (BBP, benzoic acid, phenol), and dioxins/furans, depending on the area.

3.2.1.2 Updated Interpolation Results

RAL exceedance area maps based on indicator kriging for PCBs and Thiessen polygons for other COCs were updated by incorporating Phase III data and, if appropriate, revised spatial correlation structures, as summarized in Attachment A.4. Indicator kriging contours used to delineate PCB RAL exceedance areas are presented for surface sediment (Maps A.4-4a through A.4-4c), subsurface sediment (Maps A.4-5a through A.4-5c), and combined surface and subsurface sediment (Maps A.4-6a through A.4-6c). The indicator kriging contours represent the probabilities of exceeding applicable RALs, expressed in units of percent. The 50% probability of exceedance contour represents the median estimate of the horizontal RAL exceedance area boundary. Other contours are provided for comparison, including the 20%, 30%, 40%, 60%, 70%, and 80% probabilities of exceedance. Maps A.4-8a through A.4-8c show the median (50%) PCB RAL exceedance boundary overlain with Thiessen polygons for other COCs that extend beyond the median PCB boundary. This interpolation approach is consistent with those used in previous phases of RD.

The primary results and conclusions of the interpolation update (including Phase III data) are summarized below:

- In surface sediments, there was only a nominal (2%) increase in the upper reach sample count due to the addition of Phase III data. As a result, the Phase II semivariograms were still valid to use to define surface sediment correlation structures. In subsurface sediments, there was a more significant (12%) increase in the sample count with the addition of Phase III data. Therefore, the semivariograms for subsurface sediments were re-evaluated and correlation structures were improved.
- The addition of Phase III subsurface data allowed for the resolution of anisotropy[6] in the correlation structures of the middle and lower segments, which expanded the correlation range along the direction of current/tidal flow, approximately parallel to the shoreline and the bathymetric contours. Anisotropic correlation structures are common and expected in long, narrow waterways like the LDW, with prevailing directions of river currents and tides. The

[6] Anisotropy is a directionally defined correlation structure with longer correlation scales along one axis (the predominant direction of flow) and shorter correlation scales perpendicular to that axis (flow). Nugget and sill values remain constant and directionally independent.

anisotropic correlation structures developed using the Phase III design dataset confirmed that the RD process is sufficiently robust to effectively address RAL exceedance areas, regardless of whether those exceedance areas are modeled using isotropic or anisotropic methods.

- One of the Phase III sampling objectives was to collect data in areas of higher uncertainty to help constrain the indicator probability contours and increase the confidence of the RAL exceedance area boundaries in those areas. This Phase III sampling objective was achieved.
- In some of the new Phase III data collection areas, RAL exceedances were observed outside the 60% RD RAA (based on Phase II RAL exceedance areas), and/or non-exceedances were observed inside the 60% RD RAA. In such areas, RD modifications were made during 90% RD, as needed.
- There were only minor changes to the Thiessen polygon boundaries, which were used to delineate RAL exceedance areas for COCs other than PCBs. Those changes had a minimal effect on the 90% RD.

RAL exceedance areas are depicted in Map A-6 using the design dataset. These RAL exceedance areas form the foundation for 90% RD, prior to engineering considerations. See Maps A.4-8a through A.4-8e in Attachment A.4 for further details.

4 Next Steps

The Phase III data outlined in this appendix have been incorporated into the design dataset used for 90% RD. No data gaps remain to complete RD. Once 100% RD has been approved, the design dataset and relevant GIS files will be posted to https://ldwg.org/, and PDI data will be submitted to the Washington State Department of Ecology's Environmental Information Management database and EPA's Scribe database, as described in the PDI Work Plan.

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Appendix A – PDI Phase III Data Report for the LDW Upper Reach

Attachment A.1
Mudline Elevations and Coordinates for Phase III Samples

Appendix A – PDI Phase III Data Report for the LDW Upper Reach

Attachment A.1
Mudline Elevations and Coordinates
for Phase III Samples

This file is an attachment to the Phase III Data Report for the Lower Duwamish Waterway Upper Reach.

Attachment A.1 Table of Contents

Table A.1-1. Phase III Surface Sediment Coordinates

Location Category	Location Type	Location ID	Location ID	Collection Date	Collection Method	Mudline Elevation (ft MLLW)	Elevation Type	River Mile	Reoccupy Location	Target Coordinates		Actual Coordinates		Distance from Target (ft)
										X	Y	X	Y	
Surface sediment	0-10 cm sediment grab	LDW22-SS766	766	12/6/2022	Power grab	-0.45	LDW RTK tide station	3.3	DR203	1274270	196653	1274271.9	196656.2	3.7
Surface sediment	0-10 cm sediment grab	LDW22-SS771	771	12/6/2022	Power grab	-3.32	LDW RTK tide station	3.5		1275130	195853	1275128.3	195850.2	3.1
Surface sediment	0-10 cm sediment grab	LDW22-SS772	772	12/6/2022	Power grab	-4.68	LDW RTK tide station	3.5	LDW-SS2214-U	1275134	195819	1275138.3	195825.6	7.8
Surface sediment	0-10 cm sediment grab	LDW22-SS773	773	12/2/2022	Hand collected	6.45	Bathymetric Elevation	3.5	99-G	1275094	195817	1275102.6	195812.1	9.9
Surface sediment	0-10 cm sediment grab	LDW22-SS774	774	12/2/2022	Hand collected	6.44	Bathymetric Elevation	3.5		1275114	195801	1275126.6	195787.3	18.6
Surface sediment	0-10 cm sediment grab	LDW22-SS786	786	12/6/2022	Power grab	-2.05	LDW RTK tide station	3.7	DR209	1275718	195037	1275720.5	195039.5	3.5
Surface sediment	0-10 cm sediment grab	LDW22-SS794	794	12/7/2022	Hand collected	14.4	Bathymetric Elevation	3.8		1275727	194720	1275727.0	194719.0	1.5
Surface sediment	0-10 cm sediment grab	LDW22-SS797	797	12/7/2022	Hand collected	9.74	Bathymetric Elevation	3.8		1275732	194684	1275732.3	194684.6	1
Surface sediment	0-10 cm sediment grab	LDW22-SS811	811	12/6/2022	Power grab	-7.84	LDW RTK tide station	4.0		1276276	193750	1276276.3	193751.0	1.4
Surface sediment	0-10 cm sediment grab	LDW22-SS812	812	12/7/2022	Hand collected	7.5	LDW RTK tide station	4.2	04-intsed-3	1277194	192953	1277189.4	192953.0	4.6
Surface sediment	0-10 cm sediment grab	LDW22-SS818	818	12/6/2022	Power grab	-1.36	LDW RTK tide station	4.8	R79	1277664	190514	1277666.2	190514.3	2.2
Surface sediment	0-10 cm sediment grab	LDW22-SS819	819	12/6/2022	Power grab	-8.26	LDW RTK tide station	4.8	DR254	1277888	190434	1277887.3	190432.0	2.1
Surface sediment	0-10 cm sediment grab	LDW22-SS820	820	12/6/2022	Power grab	-5.37	LDW RTK tide station	4.9		1278409	190269	1278411.1	190251.3	17.6
Surface sediment	0-10 cm sediment grab	LDW22-SS821	821	12/6/2022	Power grab	-4.34	LDW RTK tide station	4.9		1278437	190197	1278439.3	190196.4	2.3
Surface sediment	0-10 cm sediment grab	LDW22-SS822	822	12/6/2022	Power grab	-4.69	LDW RTK tide station	4.9		1278472	190175	1278470.6	190175.2	1.3
Surface sediment	0-10 cm sediment grab	LDW22-SS823	823	12/6/2022	Power grab	2.9	LDW RTK tide station	4.9	NFK005	1278643	190121	1278638.2	190116.6	6.5
Surface sediment	0-10 cm sediment grab	LDW22-SS824	824	12/6/2022	Power grab	7.42	LDW RTK tide station	4.7		1277246	189848	1277242.1	189845.1	5
Surface sediment	0-10 cm sediment grab	LDW22-SS825	825	12/6/2022	Power grab	5.95	LDW RTK tide station	4.7		1277248	189880	1277243.4	189869.3	11.5
Surface sediment	0-10 cm sediment grab	LDW22-SS826	826	3/2/2023	Power grab	-2.1	LDW RTK tide station	3.5	T117-SE-84-G	1275123	195810	1275121.9	195818.2	8.3

Table A.1-2. Phase III Subsurface Sediment Core Coordinates

Location Category	Location Type	Location ID	Location ID	Collection Date	Collection Method	Mudline Elevation (ft MLLW)	Elevation Type	River Mile	Reoccupy Location	Target Coordinates		Actual Coordinates		Distance from Target (ft)
										X	Y	X	Y	
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC750	750	12/12/2022	Vibracore	-6.3	LDW RTK tide station	3.0		1273269	197621	1273266.9	197617.2	4
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC751	751	12/7/2022	Vibracore	-13.6	LDW RTK tide station	3.0		1273287	197643	1273286.7	197641.8	1.3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC752	752	12/12/2022	Vibracore	-7.53	LDW RTK tide station	3.0		1273388	197515	1273383.8	197513.2	5.2
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC753	753	12/7/2022	Vibracore	-13.4	LDW RTK tide station	3.0		1273404	197534	1273407.2	197537.9	5
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC754	754	12/13/2022	Vibracore	-9.69	LDW RTK tide station	3.1		1273478	197435	1273481.4	197443.3	9.3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC755	755	12/7/2022	Vibracore	-14.71	LDW RTK tide station	3.1	LDW21-SC519	1273499	197457	1273501.0	197460.7	4.2
Subtidal	0-60 cm sediment core	LDW22-SC756	756	12/5/2022	Vibracore	-17.76	LDW RTK tide station	3.1		1273668	197401	1273671.1	197397.5	5.1
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC757	757	12/13/2022	Vibracore	-8.76	LDW RTK tide station	3.1		1273708	197229	1273704.5	197225.4	4.8
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC758	758	12/8/2022	Vibracore	-13.25	LDW RTK tide station	3.1		1273728	197252	1273727.4	197248.7	3.6
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC759	759	12/9/2022	Vibracore	-17.03	LDW RTK tide station	3.1		1273858	197259	1273858.1	197260.3	1.3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC760	760	12/7/2022	Vibracore	-9.81	LDW RTK tide station	3.2		1273863	197087	1273864.5	197090.7	3.7
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC761	761	12/8/2022	Vibracore	-12.95	LDW RTK tide station	3.2		1273884	197111	1273888.5	197107.2	5.3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC762	762	12/7/2022	Vibracore	-14.4	LDW RTK tide station	3.2		1273978	197019	1273981.0	197018.3	3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC763	763	12/7/2022	Vibracore	-16.04	LDW RTK tide station	3.2		1274237	196962	1274250.0	196947.8	18.7
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC764	764	12/6/2022	Vibracore	-15.48	LDW RTK tide station	3.3		1274405	196819	1274399.9	196818.6	5.2
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC765	765	12/13/2022	Vibracore	-21.16	LDW RTK tide station	3.4	LDW2-SC15	1274714	196536	1274711.0	196540.1	4.8
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC767	767	12/9/2022	Vibracore	-6.56	LDW RTK tide station	3.3		1274592	196474	1274591.9	196472.7	1.3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC768	768	12/6/2022	Vibracore	-11.84	LDW RTK tide station	3.3		1274611	196497	1274601.4	196493.2	10.3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC769	769	12/6/2022	Vibracore	-9.39	LDW RTK tide station	3.4		1274858	196285	1274856.4	196284.1	2
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC770	770	12/6/2022	Vibracore	-9.07	LDW RTK tide station	3.4	LDW13	1274895	196242	1274899.0	196239.7	4.5
Subtidal	0-60 cm sediment core	LDW22-SC771	771	12/5/2022	Vibracore	-2.88	LDW RTK tide station	3.5		1275130	195853	1275125.5	195851.5	4.7
Subtidal	0-60 cm sediment core	LDW22-SC772	772	12/5/2022	Vibracore	-4.81	LDW RTK tide station	3.5	LDW-SS2214-U	1275134	195819	1275139.7	195823.5	7.3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC775	775	12/5/2022	Vibracore	-9.36	LDW RTK tide station	3.5	LDW14	1275296	195888	1275303.0	195885.0	7.2
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC776	776	12/6/2022	Vibracore	-11.68	LDW RTK tide station	3.6		1275523	195663	1275525.8	195664.0	2.6
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC777	777	12/9/2022	Vibracore	-16.7	LDW RTK tide station	3.6		1275596	195697	1275594.0	195696.5	2.2
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC778	778	12/9/2022	Vibracore	-19.52	LDW RTK tide station	3.6		1275642	195716	1275638.8	195715.0	3.4
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC779	779	12/9/2022	Vibracore	-16.17	LDW RTK tide station	3.6		1275710	195550	1275710.0	195552.6	2.5
Subtidal	0-60 cm sediment core	LDW22-SC780	780	12/5/2022	Vibracore	-8.7	LDW RTK tide station	3.6		1275593	195544	1275587.7	195542.3	6
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC781	781	12/13/2022	Vibracore	-8.9	LDW RTK tide station	3.6		1275612	195487	1275609.0	195486.9	3.2
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC782	782	12/5/2022	Vibracore	-11.95	LDW RTK tide station	3.6		1275636	195492	1275635.0	195488.0	4.2
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC783	783	12/12/2022	Vibracore	-9.8	LDW RTK tide station	3.6	LDW21-SC573	1275666	195365	1275668.3	195366.1	2.6
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC784	784	12/5/2022	Vibracore	-12.44	LDW RTK tide station	3.6		1275689	195373	1275692.0	195371.0	3
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC785	785	12/5/2022	Vibracore	-11.19	LDW RTK tide station	3.7		1275708	195276	1275713.0	195271.0	6.5
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC787	787	12/8/2022	Vibracore	-14	LDW RTK tide station	3.7		1275929	195015	1275928.2	195014.4	1.1
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC788	788	12/13/2022	Vibracore	-11.93	LDW RTK tide station	3.7		1275965	195026	1275964.2	195027.4	1.5
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT789	789	12/8/2022	Vibracore	-0.1	LDW RTK tide station	3.7		1276047	194993	1276043.4	194990.3	4.4
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT790	790	12/8/2022	Vibracore	0.96	LDW RTK tide station	3.8		1276055	194896	1276054.6	194899.5	3.2
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT791	791	12/13/2022	Vibracore	3.09	LDW RTK tide station	3.7		1275710	194923	1275718.1	194926.5	8.9
Intertidal	0-45 cm sediment core	LDW22-IT792	792	12/5/2022	Vibracore	3.97	LDW RTK tide station	3.8		1275741	194809	1275743.1	194807.8	2.7
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT793	793	12/12/2022	Vibracore	4.5	LDW RTK tide station	3.8		1275749	194742	1275747.9	194738.0	4.6
Intertidal	0-45 cm sediment core	LDW22-IT794	794	12/7/2022	Hand collected	14.4	Bathymetric Elevation	3.8		1275727	194720	1275727.0	194719.0	1.5
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT795	795	12/12/2022	Vibracore	5.49	LDW RTK tide station	3.8	LDW21-IT66	1275745	194700	1275744.6	194696.9	3.1
Intertidal	0-45 cm sediment core	LDW22-IT796	796	12/5/2022	Vibracore	-3.25	LDW RTK tide station	3.8		1275803	194711	1275803.1	194712.8	1.8
Intertidal	0-45 cm sediment core	LDW22-IT797	797	12/7/2022	Hand collected	9.74	Bathymetric Elevation	3.8		1275732	194684	1275732.3	194684.6	1
Intertidal	0-45 cm sediment core	LDW22-IT798	798	12/5/2022	Vibracore	5.32	LDW RTK tide station	3.8		1275753	194665	1275751.7	194665.4	1.4
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT799	799	12/13/2022	Vibracore	3.7	LDW RTK tide station	3.9		1275826	194306	1275832.0	194299.4	8.9
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC800	800	12/12/2022	Vibracore	-7.85	LDW RTK tide station	3.8		1276092	194553	1276094.1	194553.9	2.3
Subtidal	0-60 cm sediment core	LDW22-SC801	801	12/7/2022	Vibracore	-8.41	LDW RTK tide station	3.8		1276120	194415	1276121.1	194419.7	4.6
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC802	802	12/8/2022	Vibracore	-12.87	LDW RTK tide station	3.9	LDW17	1276123	194239	1276123.1	194240.9	2.1
Subtidal	0-60 cm sediment core	LDW22-SC803	803	12/7/2022	Vibracore	-8.23	LDW RTK tide station	3.9		1276151	194291	1276150.4	194287.5	3.5

Table A.1-2. Phase III Subsurface Sediment Core Coordinates

Location Category	Location Type	Location ID	Location ID	Collection Date	Collection Method	Mudline Elevation (ft MLLW)	Elevation Type	River Mile	Reoccupy Location	Target Coordinates		Actual Coordinates		Distance from Target (ft)
										X	Y	X	Y	
Subtidal	0-60 cm vertical extent sediment core	LDW22-SC804	804	12/12/2022	Vibracore	-8.21	LDW RTK tide station	3.9	LDW21-SC62	1276165	194247	1276164.5	194239.4	7.7
Intertidal	0-45 cm sediment core	LDW22-IT805	805	12/7/2022	Vibracore	3.51	LDW RTK tide station	3.9		1276298	194288	1276293.4	194286.8	5.2
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT806	806	12/12/2022	Vibracore	3.23	LDW RTK tide station	3.9	LDW-SSSP1-U	1275890	194057	1275887.2	194064.6	8.1
Intertidal	0-45 cm sediment core	LDW22-IT807	807	12/7/2022	Vibracore	2.67	LDW RTK tide station	3.9		1276378	193929	1276373.7	193934.3	6.5
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT808	808	12/12/2022	Vibracore	0.38	LDW RTK tide station	4.0		1276339	193880	1276340.3	193880.9	1.6
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT809	809	12/9/2022	Vibracore	1.75	LDW RTK tide station	4.0		1276398	193852	1276382.1	193848.8	15.9
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT810	810	12/9/2022	Vibracore	1.46	LDW RTK tide station	4.0		1276416	193738	1276414.4	193733.0	5.2
Subtidal	0-60 cm sediment core	LDW22-SC813	813	12/5/2022	Vibracore	-8.39	LDW RTK tide station	4.2		1277356	192897	1277350.9	192894.5	5.6
Intertidal	0-45 cm vertical extent sediment core	LDW22-IT814	814	12/9/2022	Vibracore	0.95	LDW RTK tide station	4.7	LDW21-IT697	1277570	190025	1277568.4	190053.8	28.9
Intertidal	0-45 cm sediment core	LDW22-IT815	815	12/5/2022	Vibracore	1.27	LDW RTK tide station	4.7		1277570	190062	1277566.2	190060.5	4
Intertidal	0-45 cm sediment core	LDW22-IT816	816	12/5/2022	Vibracore	-0.24	LDW RTK tide station	4.7		1277608	190058	1277608.3	190054.6	3.4
Intertidal	0-45 cm sediment core	LDW22-IT817	817	12/5/2022	Vibracore	1.56	LDW RTK tide station	4.7		1277572	189969	1277572.1	189966.8	2.1

Table A.1-3. Comparison of RTK and Bathymetric Elevations for Phase III PDI Subsurface Sediment Locations

Location ID	PDI Phase	Sample Type	Sample Collection Date	Collection Time	Sample Collection Method	Water Depth (ft)	Tide / Water Level Height (ft MLLW)	RTK Mudline Elevation (ft MLLW)	Bathymetric Mudline Elevation (ft MLLW)	Elevation Difference (ft)
750	Phase III	0-60 cm vertical extent sediment core	12/12/2022	09:26	Vibracore	-18.4	12.08	-6.3	-5.73	-0.6
751	Phase III	0-60 cm vertical extent sediment core	12/7/2022	10:56	Vibracore	-21.1	7.50	-13.6	-11.42	-2.2
752	Phase III	0-60 cm vertical extent sediment core	12/12/2022	11:01	Vibracore	-18.1	10.57	-7.5	-7.03	-0.5
753	Phase III	0-60 cm vertical extent sediment core	12/7/2022	10:08	Vibracore	-21.3	7.63	-13.4	-11.74	-1.7
754	Phase III	0-60 cm vertical extent sediment core	12/13/2022	15:28	Vibracore	-16.6	6.91	-9.7	-8.96	-0.7
755	Phase III	0-60 cm vertical extent sediment core	12/7/2022	09:20	Vibracore	-22.9	8.19	-14.7	-12.35	-2.4
756	Phase III	0-60 cm sediment core	12/5/2022	09:33	Vibracore	-24.5	6.74	-17.8	-17.17	-0.6
757	Phase III	0-60 cm vertical extent sediment core	12/13/2022	13:36	Vibracore	-16.7	7.94	-8.8	-7.31	-1.5
758	Phase III	0-60 cm vertical extent sediment core	12/8/2022	14:29	Vibracore	-23.0	9.75	-13.3	-12.17	-1.1
759	Phase III	0-60 cm vertical extent sediment core	12/9/2022	09:58	Vibracore	-27.1	10.07	-17.0	-16.82	-0.2
760	Phase III	0-60 cm vertical extent sediment core	12/7/2022	13:30	Vibracore	-19.2	9.39	-9.8	-9.1	-0.7
761	Phase III	0-60 cm vertical extent sediment core	12/8/2022	13:47	Vibracore	-22.1	9.15	-13.0	-12.7	-0.3
762	Phase III	0-60 cm vertical extent sediment core	12/7/2022	14:14	Vibracore	-24.4	10.00	-14.4	-12.28	-2.1
763	Phase III	0-60 cm vertical extent sediment core	12/7/2022	13:22	Vibracore	-25.2	9.16	-16.0	-16.12	0.1
764	Phase III	0-60 cm vertical extent sediment core	12/6/2022	14:06	Vibracore	-26.1	10.62	-15.5	-16.5	1.0
765	Phase III	0-60 cm vertical extent sediment core	12/13/2022	12:14	Vibracore	-30.6	9.44	-21.2	-20.41	-0.8
767	Phase III	0-60 cm vertical extent sediment core	12/9/2022	12:45	Vibracore	-14.9	8.34	-6.6	-5.22	-1.3
768	Phase III	0-60 cm vertical extent sediment core	12/6/2022	12:04	Vibracore	-20.5	8.66	-11.8	-9.23	-2.6
769	Phase III	0-60 cm vertical extent sediment core	12/6/2022	10:03	Vibracore	-16.6	7.21	-9.4	-10.35	1.0
770	Phase III	0-60 cm vertical extent sediment core	12/6/2022	09:04	Vibracore	-16.5	7.43	-9.1	-9.24	0.2
771	Phase III	0-60 cm sediment core	12/5/2022	08:33	Vibracore	-9.5	6.62	-2.9	-3.06	0.2
772	Phase III	0-60 cm sediment core	12/5/2022	08:15	Vibracore	-11.5	6.69	-4.8	-5.12	0.3
775	Phase III	0-60 cm vertical extent sediment core	12/5/2022	09:37	Vibracore	-16.1	6.74	-9.4	-9.76	0.4
776	Phase III	0-60 cm vertical extent sediment core	12/6/2022	07:49	Vibracore	-20.3	8.62	-11.7	-10.5	-1.2
777	Phase III	0-60 cm vertical extent sediment core	12/9/2022	08:52	Vibracore	-27.8	11.24	-16.7	-15.49	-1.2
778	Phase III	0-60 cm vertical extent sediment core	12/9/2022	07:56	Vibracore	-31.5	11.98	-19.5	-18.76	-0.8
779	Phase III	0-60 cm vertical extent sediment core	12/9/2022	08:09	Vibracore	-28.0	11.83	-16.2	-15.5	-0.7
780	Phase III	0-60 cm sediment core	12/5/2022	10:23	Vibracore	-16.0	7.30	-8.7	-8.38	-0.3
781	Phase III	0-60 cm vertical extent sediment core	12/13/2022	11:00	Vibracore	-19.8	10.90	-8.9	-7.21	-1.7
782	Phase III	0-60 cm vertical extent sediment core	12/5/2022	11:22	Vibracore	-20.3	8.35	-12.0	-10.45	-1.5
783	Phase III	0-60 cm vertical extent sediment core	12/12/2022	12:59	Vibracore	-18.0	8.20	-9.8	-8.3	-1.5
784	Phase III	0-60 cm vertical extent sediment core	12/5/2022	12:20	Vibracore	-22.1	9.66	-12.4	-11.16	-1.3
785	Phase III	0-60 cm vertical extent sediment core	12/5/2022	13:54	Vibracore	-22.3	11.11	-11.2	-10.11	-1.1
787	Phase III	0-60 cm vertical extent sediment core	12/8/2022	11:27	Vibracore	-22.8	8.10	-14.0	-13.89	-0.1
788	Phase III	0-60 cm vertical extent sediment core	12/13/2022	10:28	Vibracore	-23.2	11.27	-11.9	-11.56	-0.4
789	Phase III	0-45 cm vertical extent sediment core	12/8/2022	8:17	Vibracore	-11.2	11.15	-0.1	-0.01	-0.1
790	Phase III	0-45 cm vertical extent sediment core	12/8/2022	09:20	Vibracore	-9.0	9.96	1.0	-0.27	1.2
791	Phase III	0-45 cm vertical extent sediment core	12/13/2022	09:50	Vibracore	-8.6	11.69	3.1	NR	na
792	Phase III	0-45 cm sediment core	12/5/2022	11:00	Vibracore	-4.1	8.07	4.0	5.31	-1.3
793	Phase III	0-45 cm vertical extent sediment core	12/12/2022	08:26	Vibracore	-7.8	12.30	4.5	6.05	-1.6
794	Phase III	0-45 cm sediment core	12/7/2022	11:10	Hand collected	NR	7.66	NR	14.4	na
795	Phase III	0-45 cm vertical extent sediment core	12/12/2022	07:47	Vibracore	-6.6	12.09	5.5	6.95	-1.5
796	Phase III	0-45 cm sediment core	12/5/2022	11:25	Vibracore	-11.6	8.35	-3.3	-2.01	-1.2
797	Phase III	0-45 cm sediment core	12/7/2022	10:10	Hand collected	NR	7.51	NR	9.74	na
798	Phase III	0-45 cm sediment core	12/5/2022	11:43	Vibracore	-3.7	9.02	5.3	6.22	-0.9
799	Phase III	0-45 cm vertical extent sediment core	12/13/2022	08:13	Vibracore	-7.9	11.54	3.7	4.61	-0.9
800	Phase III	0-60 cm vertical extent sediment core	12/12/2022	12:14	Vibracore	-16.9	9.05	-7.9	-8.81	1.0
801	Phase III	0-60 cm sediment core	12/7/2022	12:17	Vibracore	-16.7	8.29	-8.4	-8.78	0.4
802	Phase III	0-60 cm vertical extent sediment core	12/8/2022	10:39	Vibracore	-21.4	8.53	-12.9	-12.37	-0.5
803	Phase III	0-60 cm sediment core	12/7/2022	12:35	Vibracore	-16.7	8.47	-8.2	-8.87	0.6

Table A.1-3. Comparison of RTK and Bathymetric Elevations for Phase III PDI Subsurface Sediment Locations

Location ID	PDI Phase	Sample Type	Sample Collection Date	Collection Time	Sample Collection Method	Water Depth (ft)	Tide / Water Level Height (ft MLLW)	RTK Mudline Elevation (ft MLLW)	Bathymetric Mudline Elevation (ft MLLW)	Elevation Difference (ft)
804	Phase III	0-60 cm vertical extent sediment core	12/12/2022	11:18	Vibracore	-18.5	10.29	-8.2	-9	0.8
805	Phase III	0-45 cm sediment core	12/7/2022	08:40	Vibracore	-5.6	9.11	3.5	NR	na
806	Phase III	0-45 cm vertical extent sediment core	12/12/2022	08:35	Vibracore	-9.1	12.33	3.2	4.64	-1.4
807	Phase III	0-45 cm sediment core	12/7/2022	09:10	Vibracore	-5.8	8.47	2.7	NR	na
808	Phase III	0-45 cm vertical extent sediment core	12/12/2022	9:46	Vibracore	-11.4	11.78	0.4	0.43	-0.1
809	Phase III	0-45 cm vertical extent sediment core	12/9/2022	11:44	Vibracore	-6.5	8.25	1.8	2.19	-0.4
810	Phase III	0-45 cm vertical extent sediment core	12/9/2022	08:40	Vibracore	-10.0	11.46	1.5	2.11	-0.6
813	Phase III	0-60 cm sediment core	12/5/2022	13:45	Vibracore	-19.5	11.11	-8.4	-8.91	0.5
814	Phase III	0-45 cm vertical extent sediment core	12/9/2022	12:40	Vibracore	-7.3	8.25	1.0	1.57	-0.6
815	Phase III	0-45 cm sediment core	12/5/2022	12:42	Vibracore	-9.0	10.27	1.3	1.48	-0.2
816	Phase III	0-45 cm sediment core	12/5/2022	12:22	Vibracore	-9.9	9.66	-0.2	1.22	-1.5
817	Phase III	0-45 cm sediment core	12/5/2022	12:55	Vibracore	-9.0	10.56	1.6	2.37	-0.8

Appendix A – PDI Phase III Data Report for the LDW Upper Reach

Attachment A.2
Topographic Survey Data Report and Bank Features

Introduction

This attachment to the *Phase III Data Report for the Lower Duwamish Waterway Upper Reach* presents detailed information related to the topographic surveying activities conducted as part of the Lower Duwamish Waterway (LDW) upper reach Phase III Pre-Design Investigation (PDI) by True North Land Surveying, Inc. (True North), the professional land surveyor. During Preliminary (30%) remedial design (RD), data gaps among previous bathymetric and topographic surveys in areas of proposed remedial construction were identified (Anchor QEA and Windward 2022a). This Phase III PDI topographic survey augmented data collected during previous bathymetric and topographic surveys conducted from 2019 through 2021, as well as King County's light detection and ranging (LiDAR) data, which provided elevation data above approximately 0 feet mean lower low water. Generally, the areas with data gaps were 1) where the bank elevation was too high to collect data using bathymetric surveying and 2) where the land was inaccessible to the land surveyors in 2021.

To support RD, two types of information were needed in the remedial action level (RAL) exceedance areas adjacent to banks: detailed elevation contours and extents of features (e.g., structures, bank armoring, woody vegetation) that may affect the design and implementation of remedial actions. This information was used in Pre-Final (90%) RD to help clarify bank site conditions that remedial action construction could disturb, and to design remedial actions to minimize impacts at bank locations above mean higher high waters. Topographic data and bank features information informed habitat inventory, remedial technology design, and slope stability analyses.

Survey Methods

This additional topographic survey was performed as described in the *Quality Assurance Project Plan Addendum for the Lower Duwamish Waterway Upper Reach: Supplemental Topographic Survey Phase III* (Anchor QEA and Windward 2022b). The survey began on October 5, 2022, with an overview of the areas and identification of features that needed to be delineated for design, and it was completed on October 7, 2022. To gather data that overlapped with bathymetric survey data, the topographic survey was performed at low tide and to the top of bank or, for lower banks, to approximately 50 feet landward of mean higher high water. The horizontal datum for this survey was North American Datum of 1983, 1991 adjustment, State Plane Coordinate System, Washington North Zone, measured in U.S. Survey Feet, and the vertical datum was mean lower low water (North American Vertical Datum 88 +2.34').

The additional topographic survey was performed in RAL exceedance areas adjacent to banks (Areas 13, 18, 19, 20, 22, 24, 25, 26, 33, and 34) using global positioning system (GPS) and total station instruments. True North established multiple control points at each RAL exceedance area where topographic surveying was performed using the control network established prior to the 2019 bathymetric survey. The geodetic control survey was conducted using GPS techniques from monuments with published positions and elevations.

The equipment used for the survey and associated precision of each instrument are as follows:

- Leica TS16 (Total Station), precision is 0.5 inches horizontally and vertically
- Leica GS16 (GPS RTK Unit), precision is 8.0 millimeters (mm) +1 parts per million horizontally and 15 mm +1 parts per million vertically
- Leica LS10 (Digital Level with Bar Code Rod), 0.3 mm vertically.

Data were collected using a 25-foot grid-like pattern, as well as at break lines (tops and toes of slopes) and significant changes in existing surfaces. The extents of significant surface bank features (e.g., structures, bank armoring, vegetation, utilities, debris) were determined by taking survey shots at corners of rectilinear features or, for curvilinear features, at changes of curvature.

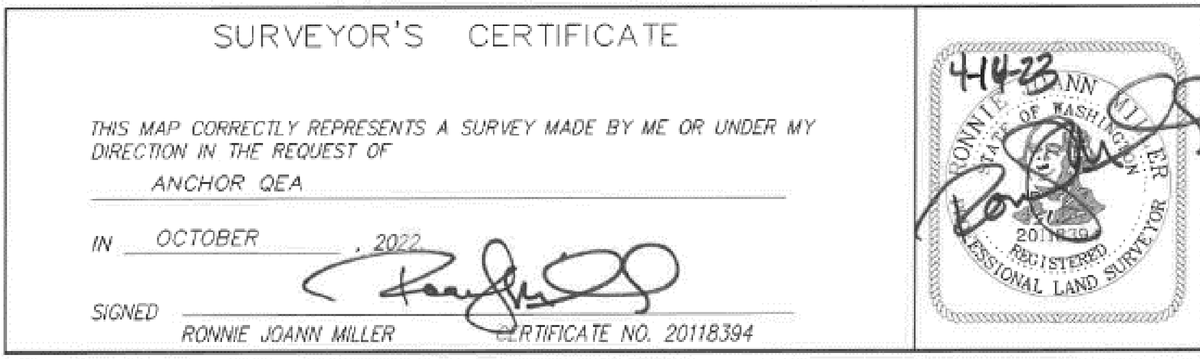
The results of the survey in each RAL exceedance area are included in the RD maps. The figures in the *Supplement to the Quality Assurance Project Plan Addendum: Pre-Design Surveys of the Lower Duwamish Waterway Upper Reach* show the proposed limits of the survey, bathymetric and topographic contours, and the locations of surface features (Anchor QEA and Windward 2022c). The topographic survey overlapped with the bathymetric survey at all locations.

Near Area 13, the scope of the additional topographic survey work associated with the RAL exceedance was limited to locating an outfall pipe. The scope in Areas 18, 22, and 24 was to locate additional outfall pipes, debris, the toe of the existing walls, and (in Area 24) a building. For Areas 33 and 34, right-of-entry could not be obtained, so outfall pipes were not located; however, the surveyors were able to collect topographic data on the area from their vessel, mainly behind a line of piles positioned under water and continuing up the slope.

Deliverable

Topographic data were used to develop surface contours for each of the surveyed areas. The results of the topographic survey were provided in a drawing file (.dwg). (.xml), and a coordinate file (.txt). The drawing file displays the topographic contours and the limits of surface features identified as potentially significant during the initial site visit.

Signature



SURVEYOR'S CERTIFICATE

THIS MAP CORRECTLY REPRESENTS A SURVEY MADE BY ME OR UNDER MY DIRECTION IN THE REQUEST OF

ANCHOR QEA

IN OCTOBER, 2022

SIGNED

RONNIE JOANN MILLER CERTIFICATE NO. 20118394

4-14-23

References

Anchor QEA, Windward. 2022a. Preliminary (30%) remedial design basis of design report for Lower Duwamish Waterway upper reach. Submitted to EPA August 29, 2022. Anchor QEA and Windward Environmental LLC, Seattle, WA.

Anchor QEA, Windward. 2022b. Quality assurance project plan addendum for the Lower Duwamish Waterway Upper Reach: supplemental topographic survey Phase III. Draft. For submittal to EPA September 2, 2022. Anchor QEA and Windward Environmental LLC, Seattle, WA.

Anchor QEA, Windward. 2022c. Supplement to the quality assurance project plan addendum: pre-design surveys of the Lower Duwamish Waterway Upper Reach. Final. Prepared for submittal to US Environmental Protection Agency September 22, 2022. Anchor QEA and Windward Environmental LLC, Seattle, WA.

Appendix A – PDI Phase III Data Report for the LDW Upper Reach

Attachment A.3
Vertical Core Diagrams with Concentrations for all PDI Locations

Attachment A.3 Vertical Core Diagrams with Concentrations for all PDI Locations

Numbers shown are total PCB concentrations in mg/kg OC unless otherwise noted.
Concentrations shown in blue with "dw" after the value are total PCB concentrations in μg/kg dw.
D/F TEQs (indicated as "DF") are in ng/kg dw.
Arsenic concentrations (indicated as "As") are in mg/kg dw.

Areas 1, 2, and 3 (RM 3 to 3.1)

Depth intervals shown: -6 to -7 ft; -7 to -8 ft; -8 to -9 ft; -9 to -10 ft; -10 to -11 ft; -11 to -12 ft; -12 to -13 ft; -13 to -14 ft; -14 to -15 ft; -15 to -17 ft MLLW; -17 to -18 ft; -18 to -19 ft; -19 to -20 ft; -20 to -21 ft; -21 to -22 ft; -22 to -23 ft; -23 to -24 ft; -24 to -25 ft; -25 to -26 ft; -26 to -27 ft; -27 to -28 ft; -28 to -29 ft; -29 to -30 ft

location ID	mudline	Intervals (top to bottom)
750	-6.3	0.59; 0.4 U; 0.4 U; 0.5 U; 0.4 U; 4 U dw; 0.3 U; 0.4 U; I
751	-13.6	A (0-60); B; C; 88; 104; 33.6; 1.83; 1.26; 4 U dw; 4 U dw; 0.5 U; L; M; N
510	-11.6	A (0-60); 150; 160; D; 28; 135 dw
509	-17.2	A (0-60); 64.7; 18.9; 3.6; 0.6 U; F; 0.2 U; H; I; J; K; L
752	-7.5	9.9; 0.6 U; 0.6 U; 0.4 U; 0.4 U; 0.2 U; 4 U dw; 4 U dw
753	-13.4	13.6; 49.7; 21.8; 17.6; 27.6; 74; 61.2; 4 U dw; 0.6 U; 0.4 U; 0.7 U; L; M; N
513	-17.5	10.2; 59.9; 12.6; 2.3; E; F; G; H; I; J; K
514	-17.5	43.6; 21.9; 9.36; D; 0.3 U; F; 4 U dw; H; I; J; K
517	-16.8	A (0-60); 58.3; 43.4; 2.6; 0.3 U; F; 0.3 U; H; I; J; K
754	-9.7	11; 1.62; 0.7 U; 4 U dw; 4 U dw; 4 U dw; 4 U dw; 0.5 U
755	-14.7	A (0-60); B; 107; 139; 88.3; 39; 23.6; 0.3 U; 0.5 U; 1.9 U; K; L; M; N
519	-11.2	17.9; 67; 144; 83.6; 102; 30.5
520	-17.4	6.69; 31.3; 0.98; D; 0.3 U; F; 0.4 U; H; I
521	-16.9	A (0-60); 48.8; 9.12; D; 3.1; F; 0.3 U; H; 0.1 U; J; K

Note: Shading added to help differentiate transects, which are presented here from west to east.

Areas 4, 5, and 6 (RM 3.1 to 3.35 Subtidal)

Depth intervals shown: -8 to -9 ft; -9 to -10 ft; -10 to -11 ft; -11 to -12 ft; -12 to -13 ft; -13 to -14 ft; -14 to -15 ft; -15 to -17 ft MLLW; -17 to -18 ft; -18 to -19 ft; -19 to -20 ft; -20 to -21 ft; -21 to -22 ft; -22 to -23 ft; -23 to -24 ft; -24 to -25 ft; -25 to -26 ft; -26 to -27 ft; -27 to -28 ft; -28 to -29 ft; -29 to -30 ft; -30 to -31 ft

location ID	mudline	Intervals (top to bottom)
757	-8.8	26.4; 5.04; 4 U dw; 4 U dw; 4 U dw; 4 U dw; 4 U dw; 4 U dw
758	-13.3	A (0-60); 124; 110; 17; 21.7; 1.89; 0.2 U; 0.1 U; 0.2 U; 0.2 U; 0.3 U; L; M
527	-16.3	A (0-60); 26.2; 96.7; 6.99; 0.3 U; F; 0.6 U; H; I; J; K
529	-11.5	39.8; 123; 103; 1.62; 22; 0.43
759	-17.0	A (0-60); 32; 81.9; 73.6; 7.3; 0.5 U; 0.3 U; 0.3 U
760	-9.8	59.9; 153; 94.9; 96.9; 97.3; 84.4; 89.8; 27.4; 36.1 dw
761	-12.9	17.1; 141; 54.3; 42.4; 64.8 dw; 111; 7.9; 0.3 U; 0.4 U; 0.7 U; 0.4 U; 4 U dw; M
531	-17.2	A (0-60); 44.7; 45.9; 4.9; 0.5 U; F; 0.3 U; H; I
762	-14.4	23.5; 77.5; 90.3; 78.7; 313 dw; 28.7 dw; 8; 0.2 U; 0.2 U; 0.2 U; K; L; M
532	-17.4	A (0-60); 72; 3.46; D; 0.3 U; F; 0.3 U; H; I
533	-17.2	A (0-60); 42.2; 3.4; D; 0.3 U; F; 0.3 U; H; I
534	-17.4	A (0-60); 83.4; 22; 5.9 dw; 0.8 U; F; 0.3 U; H; I
763	-16.0	A (0-60); B; C; D; E; F; G; H; I
535	-17.6	A (0-60); 26; 23.1; 0.85; 4 U dw; F
537	-17.7	A (0-60); 33; 0.2 U; D; 0.4 U; F
764	-15.5	A (0-60); B; C; D; 9.8 dw; 4 U dw; 4 U dw; 15 dw; 4 U dw; 4 U dw; 4 U dw; 4 U dw; 4 U dw; O
538	-19.9	A (0-60); 0.4 U; 4 U dw; D; 4 U dw; F
539	-18.9	23.6; 44.5 dw; 0.2 U; D; 4 U dw; F
553	-20.0	A (0-60); 4 U dw; 0.2 U; 0.2 U; E; F
765	-21.2	A (0-60); 24.1 dw; 9.39; 61.8; 25.7 dw; F; G; H; I
554	-18.2	5.28; 42.7; 11; 95.6; 688; 63.8

Note: Shading added to help differentiate transects, which are presented here from west to east.

RM 3.3 W Intertidal

Depth intervals shown: +1 to 0 ft; 0 to -1 ft; -1 to -2 ft; -2 to -3 ft; -3 to -4 ft; -4 to -5 ft; -5 to -6 ft; -6 to -7 ft; -7 to -8 ft; -8 to -9 ft; -9 to -10 ft

location ID	mudline	Intervals (top to bottom)
543	-3.5	72.6 dw; 6.05; 0.4; D; 3.9 dw; F
545	-0.1	A (0-45); 44.6 dw; 1.3 dw; D; 4 U dw; F

Legend

- No RAL exceedances (green)
- Exceeds RAL (red)
- Interval below RAL that exceeds surface sediment RAL (purple)
- Archive (yellow)
- Native sediment (can be any color)

Attachment A.3 Vertical Core Diagrams with Concentrations for all PDI Locations

Numbers shown are total PCB concentrations in mg/kg OC unless otherwise noted.
Concentrations shown in blue with "dw" after the value are total PCB concentrations in µg/kg dw.
D/F TEQs (indicated as "DF") are in ng/kg dw.
Arsenic concentrations (indicated as "As") are in mg/kg dw.

Area 11 (RM 3.35 Subtidal)

location ID:	767	768	148	549
mudline:	-6.6	-11.8	-12.0	-15.0
-6 to -7 ft				
-7 to -8 ft	9.3 dw			
-8 to -9 ft	4 U dw			
-9 to -10 ft	4 U dw			
-10 to -11 ft	4 U dw			
-11 to -12 ft	4 U dw			
-12 to -13 ft	4 U dw	6.58 (shoal)	shoal (0-49)	
-13 to -14 ft		4 U dw (shoal)	shoal (49-98)	
-14 to -15 ft				
-15 to -17 ft MLLW		4 U dw	5.6 (Hg, PAHs > RAL)	3.02
-17 to -18 ft		17.2 dw		4.26
-18 to -19 ft		21.4 dw		3.39
-19 to -20 ft		15.5 (FD)		D
-20 to -21 ft		35 dw		6.61
-21 to -22 ft		18		7.44
-22 to -23 ft		1.77		238 dw
-23 to -24 ft		0.71		6.53
-24 to -25 ft		0.4 U		I
-25 to -26 ft		0.2 U		J
-26 to -27 ft		M		K
-27 to -28 ft				L
-28 to -29 ft				M

Note: Hg and PAHs < RAL for Phase III samples

Area 13 (SPM)

location ID:	560
mudline:	-2.9
-3 to -4 ft	A (0-60)
-4 to -5 ft	
-5 to -6 ft	19.5
-6 to -7 ft	14.3
-7 to -8 ft	D
-8 to -10 ft (berthing depth)	26.3 98 dw
-10 to -11 ft	G
-11 to -12 ft	H
-12 to -13 ft	I

RM 3.4

location ID:	558	769	770
mudline:	-9.5	-9.4	-9.1
-9 to -10 ft			
-10 to -11 ft	2.73 (shoal)	4.4 (shoal)	2.76 (shoal)
-11 to -12 ft			
-12 to -13 ft			
-13 to -14 ft	4.69 (shoal)	6.59 (shoal)	3.92 (shoal)
-14 to -15 ft			
-15 to -17 ft MLLW	3.57	4.46	5.8
-17 to -18 ft	4.28	10.1	1.69
-18 to -19 ft	3.9	8.88	6.94
-19 to -20 ft	21.3	9.72	9
-20 to -21 ft	25.1	17.4	15.9
-21 to -22 ft	H	11.8	36.3
-22 to -23 ft	25.6	14.4	17.5
-23 to -24 ft	J	16.3	18.9
-24 to -25 ft	6.88	20	17.5
-25 to -26 ft	L		10.4
-26 to -27 ft	M		
-27 to -28 ft	N		
-28 to -29 ft	O		

RM 3.5 to 3.55 W

location ID:	564	775	565	776
mudline:	-9.3	-9.4	-10.1	-11.7
-8 to -9 ft				
-9 to -10 ft				
-10 to -11 ft	3.01 (shoal)	2.43 (shoal)	2.3 (shoal)	
-11 to -12 ft				
-12 to -13 ft				2.57 (shoal)
-13 to -14 ft	2.35 (shoal)	3.35 (shoal)	1.31 (shoal)	4.65 (shoal)
-14 to -15 ft				
-15 to -17 ft MLLW	3.14	2.09	75.1 dw	59.2
-17 to -18 ft	3.06	4.7	8.7	83.3
-18 to -19 ft	6.71	7.46	12.8	15
-19 to -20 ft	F	5.28	F	52.5
-20 to -21 ft	7.62	18.7	G	11.5
-21 to -22 ft	6.16	4.78	H	24
-22 to -23 ft	17.5	7.57	I	14.1
-23 to -24 ft	J	41.1	J	11.8
-24 to -25 ft	27.4	30.8	K	5.31
-25 to -26 ft	17	846 dw	L	226 dw
-26 to -27 ft	M	38.6	M	1.24
-27 to -28 ft	N		N	N
-28 to -29 ft				O

Area 14 and 17 (RM 3.6-3.7 E)

location ID:	777	778	568	779	576
mudline:	-16.7	-19.5	-18.4	-16.2	-16.5
-15 to -17 ft MLLW				3.93	
-17 to -18 ft	2.6				2.3
-18 to -19 ft	10.8		A (0-60)	12.3	12.9
-19 to -20 ft	56.9			16.1	6.37
-20 to -21 ft	39.5	A (0-60)	24	67.6	D
-21 to -22 ft	6.05	1.85	111	108	E
-22 to -23 ft	4.8	76.3	D	74.7	F
-23 to -24 ft	228 dw	197 dw	1031 dw	67.2	G
-24 to -25 ft	2.77	115 dw	4.88	13.5	H
-25 to -26 ft	21.7	26.2		1.04	I
-26 to -27 ft	1.55	2.66		0.5 U	J
-27 to -28 ft	0.61			K	K
-28 to -29 ft	1.46			L	L
-29 to -30 ft	5.54			M	M
-30 to -31 ft					

Area 15/16 (RM 3.6-3.65 W)

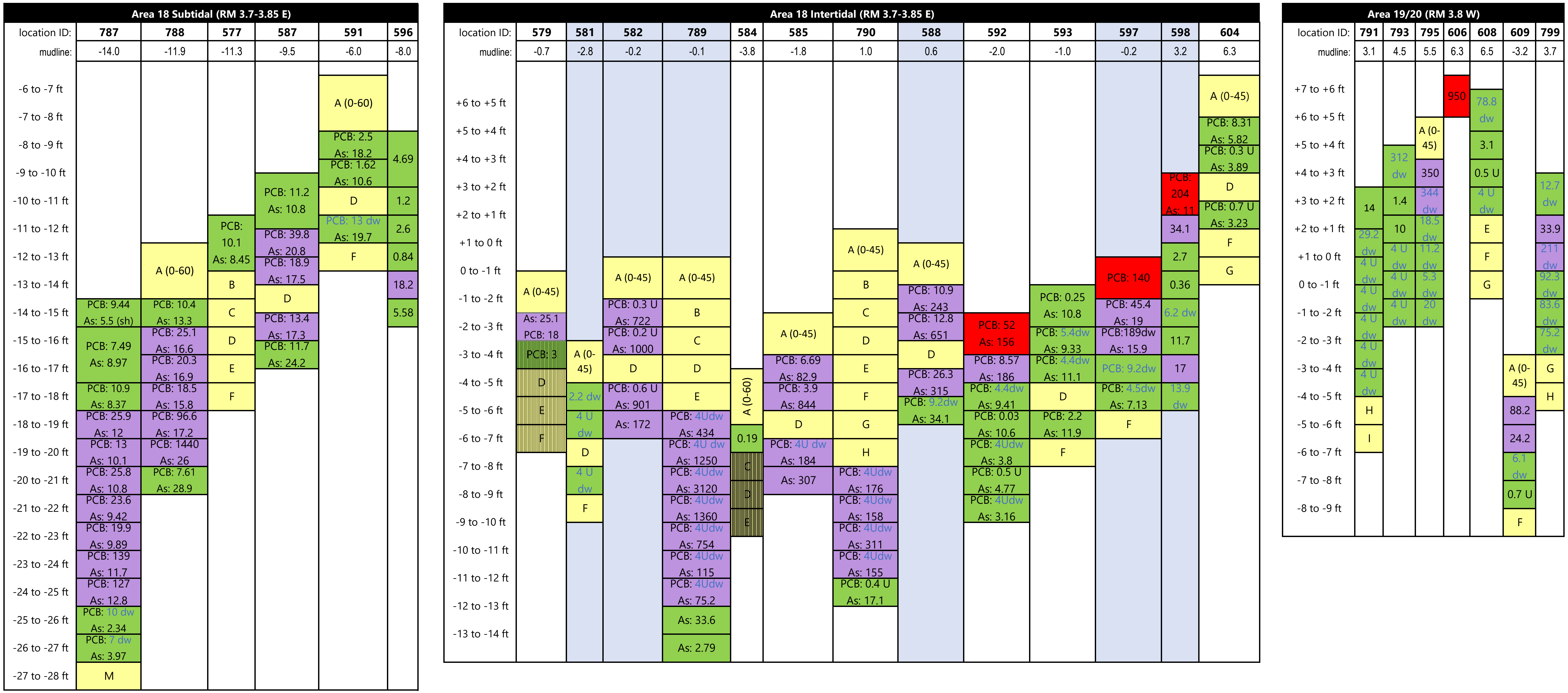
location ID:	781	782	571	T117-SE-35-SC	572	783	784	785
mudline:	-8.9	-12.0	-7.0	-11.0	-13.4	-9.8	-12.4	-11.2
-7 to -8 ft			1.8					
-8 to -9 ft								
-9 to -10 ft	A (0-60)		0.91					
-10 to -11 ft			5.33			A (0-60)		
-11 to -12 ft	25.3		D	16 (0-2 ft)		49		6.59
-12 to -13 ft	23.9	A (0-60)	0.6 U			6.8		
-13 to -14 ft	20.2			46 (2-4 ft)	2.96 shoal	48.3	A (0-60)	4.15
-14 to -15 ft	1.01	7.85				8.79	2.77	3.25
-15 to -16 ft	100 dw	5.19		18 (4-6 ft)	3.8 shoal	73.3	3.15	7.7
-16 to -17 ft	4.43	6.07				16	4.98	4.83
-17 to -18 ft	22.3	33.9		14 (6-8 ft)	7.9	15.1	8.32	7.54
-18 to -19 ft		79.3			13.8		14.8	7.32
-19 to -20 ft		45.2		2.2 (8-10 ft)	696 dw		10.4	21.3
-20 to -21 ft		52.2			F		13.7	40.3
-21 to -22 ft		52.3			20.9		13.4	29.5
-22 to -23 ft		88.2			H		8.69	18.1
-23 to -24 ft		97.6			I		3.34	24.1
-24 to -25 ft		28.6			0.932		4 U dw	23.8
-25 to -26 ft		2.78			2.2		13.6 dw	27 dw
-26 to -27 ft		0.4 U			6.6		N	O
-27 to -28 ft		O					O	P
-28 to -29 ft		P					P	
-29 to -30 ft		Q						

Legend

- No RAL exceedances
- Exceeds RAL
- Interval below RAL that exceeds surface sediment RAL
- Archive
- Native sediment (can be any color)

Attachment A.3 Vertical Core Diagrams with Concentrations for all PDI Locations

Numbers shown are total PCB concentrations in mg/kg OC unless otherwise noted.
Concentrations shown in blue with "dw" after the value are total PCB concentrations in µg/kg dw.
D/F TEQs (indicated as "DF") are in ng/kg dw.
Arsenic concentrations (indicated as "As") are in mg/kg dw.



Legend

- No RAL exceedances
- Exceeds RAL
- Interval below RAL that exceeds surface sediment RAL
- Archive
- Native sediment (can be any color)

Attachment A.3 Vertical Core Diagrams with Concentrations for all PDI Locations

Numbers shown are total PCB concentrations in mg/kg OC unless otherwise noted.
Concentrations shown in blue with "dw" after the value are total PCB concentrations in µg/kg dw.
D/F TEQs (indicated as "DF") are in ng/kg dw.
Arsenic concentrations (indicated as "As") are in mg/kg dw.

Area 21 (RM 3.8)

location ID:	800
mudline:	-7.9
-8 to -9 ft	3.95 (spans 2 rows)
-9 to -10 ft	
-10 to -11 ft	10.4
-11 to -12 ft	22.5
-12 to -13 ft	22.7
-13 to -14 ft	18
-14 to -15 ft	17.1
-15 to -16 ft	9.82
-16 to -17 ft	5.96

RM 3.9 Subtidal

location ID:	629	802
mudline:	-13.5	-12.9
-12 to -13 ft		
-13 to -14 ft	3.9 (sh) (spans 2 rows)	5.34 (sh) (spans 2 rows)
-14 to -15 ft		
-15 to -17 ft MLLW	3.75	4.84
-17 to -18 ft	6.84	8.47
-18 to -19 ft	5.31	7.56
-19 to -20 ft	E	9.71
-20 to -21 ft	6.84	16.8
-21 to -22 ft	G	155
-22 to -23 ft	8.56	178
-23 to -24 ft	I	85.2
-24 to -25 ft	78.6	4 U dw
-25 to -26 ft	K	4 U dw
-26 to -27 ft	L	L

Area 22 (RM 3.9 E)

location ID:	804	621	622
mudline:	-8.2	-1.4	0.6
0 to -1 ft			31.3
-1 to -2 ft		A (0-45) (spans 2 rows)	2.5 dw
-2 to -3 ft			4U dw
-3 to -4 ft		4 U dw	D
-4 to -5 ft		C	4U dw
-5 to -6 ft		D	F
-6 to -7 ft		E	
-7 to -8 ft		F	
-8 to -9 ft	A (0-60) (spans 2 rows)	G	
-9 to -10 ft			
-10 to -11 ft	PCB: 33 BBP: 12		
-11 to -12 ft	PCB: 52.9 dw BBP: 23.1 dw		
-12 to -13 ft	PCB: 51.9 BBP: 50		
-13 to -14 ft	PCB: 11.9 dw BBP: 20U dw		
-14 to -15 ft	PCB: 4U dw BBP: 20U dw		
-15 to -16 ft	PCB: 4U dw BBP: 20U dw		
-16 to -17 ft	PCB: 4U dw BBP: 20U dw		
-17 to -18 ft	I		
-18 to -19 ft	J		
-19 to -20 ft	K		

Area 23

location ID:	806
mudline:	3.2
+3 to +2 ft	129.2 dw
+2 to +1 ft	20.6
+1 to 0 ft	11.7
0 to -1 ft	13
-1 to -2 ft	16.1 dw
-2 to -3 ft	4U dw
-3 to -4 ft	G
-4 to -5 ft	H

RM 3.95 W

location ID:	637
mudline:	0.2
0 to -1 ft	2.2
-1 to -2 ft	21.4 dw
-2 to -3 ft	38.6 dw
-3 to -4 ft	D
-4 to -5 ft	8.6 dw
-5 to -6 ft	F

RM 3.95 to 4.0 E Subtidal

location ID:	630	634	640
mudline:	-8.5	-6.5	-4.9
-5 to -6 ft			5.6 (spans 2 rows)
-6 to -7 ft		7.93 (spans 2 rows)	
-7 to -8 ft			B
-8 to -9 ft	7.63 (spans 2 rows)	8.7	C
-9 to -10 ft		63 dw	D
-10 to -11 ft	B	D	E
-11 to -12 ft	C	0.089	F
-12 to -13 ft	D	F	
-13 to -14 ft	E		
-14 to -15 ft	F		

Area 24/25 and Area 26

location ID:	808	632	809	635	644	810
mudline:	0.4	3.1	1.8	0.9	-0.4	1.5
+3 to +2 ft		PCB: 102 DF: 12				
+2 to +1 ft		PCB: 136 DF: 104	PCB: 136 DF: 61.4			PCB: 27.9 DF: 20.3
+1 to 0 ft	PCB: 25.8 DF: 6.93	PCB: 29.7 DF: 2.94	PCB: 13.7 DF: 5.66	PCB: 107 DF: 15.3		PCB: 14.5 DF: 8.22
0 to -1 ft		PCB: 9 dw	PCB: 6.8 dw DF: 2.27	PCB: 29.2 DF: 33.2	A (0-45)	PCB: 7.18 DF: 2.35
-1 to -2 ft	PCB: 27.9 DF: 19.7	E	PCB: 7.1 dw DF: 0.508	222 dw		PCB: 1.82 DF: 2.67
-2 to -3 ft	PCB: 4U dw DF: 0.606	F	PCB: 5.3 dw DF: 0.231	4 U dw	7.27	PCB: 29.5 dw DF: 1.22
-3 to -4 ft	PCB: 0.2 U DF: 0.908		PCB: 0.3 U DF: 1.33	E	4.69	PCB: 4U dw DF: 1.07
-4 to -5 ft	PCB: 4U dw DF: 0.224		PCB: 4U dw DF: 0.366	F	3.68	PCB: 0.3 U DF: 1.65
-5 to -6 ft	PCB: 4U dw DF: 0.248		H	G	4 U dw	
-6 to -7 ft	G		I		F	
-7 to -8 ft	H					

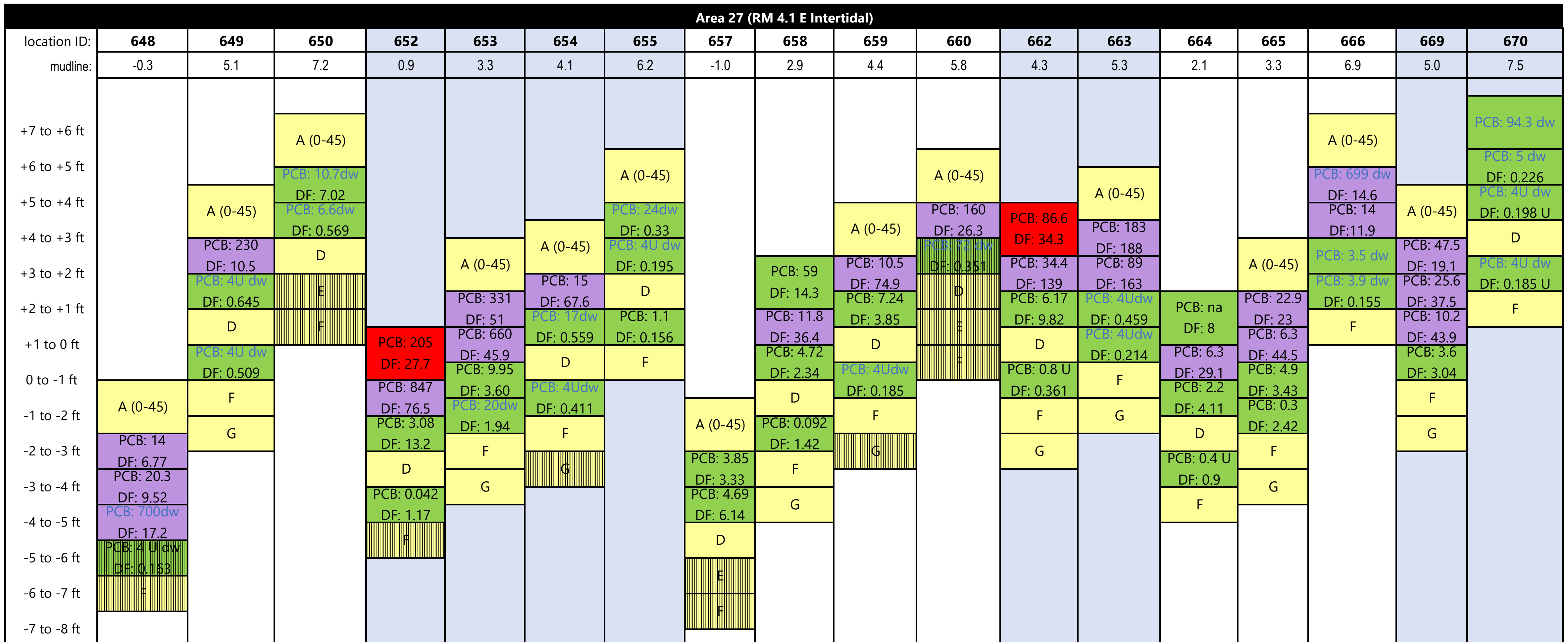
Note: Core at 809 also analyzed for BBP; non-detect for all intervals.

Legend

- No RAL exceedances (green)
- Exceeds RAL (red)
- Interval below RAL that exceeds surface sediment RAL (purple)
- Archive (yellow)
- Native sediment (can be any color) (hatched)

Attachment A.3 Vertical Core Diagrams with Concentrations for all PDI Locations

Numbers shown are total PCB concentrations in mg/kg OC unless otherwise noted.
Concentrations shown in blue with "dw" after the value are total PCB concentrations in µg/kg dw.
D/F TEQs (indicated as "DF") are in ng/kg dw.
Arsenic concentrations (indicated as "As") are in mg/kg dw.



Note: Shading added to help differentiate transects, which are presented here from west to east.

Legend

- No RAL exceedances
- Exceeds RAL
- Interval below RAL that exceeds surface sediment RAL
- Archive
- Native sediment (can be any color)

Attachment A.3 Vertical Core Diagrams with Concentrations for all PDI Locations

Numbers shown are total PCB concentrations in mg/kg OC unless otherwise noted.
Concentrations shown in blue with "dw" after the value are total PCB concentrations in µg/kg dw.
D/F TEQs (indicated as "DF") are in ng/kg dw.
Arsenic concentrations (indicated as "As") are in mg/kg dw.

Area 28 (Slip 6)			
location ID:	673a	673b	674
mudline:	-6.0		-8.3
-6 to -7 ft	2.65		
-7 to -8 ft			
-8 to -9 ft	87 dw		
-9 to -10 ft	157 dw		A (0-60)
-10 to -11 ft	D		99.9 dw
-11 to -12 ft	4.44		117 dw
-12 to -13 ft	F		D
-13 to -14 ft	5.11		4.19
-14 to -15 ft	H		F
-15 to -16 ft	8 U		4.72
-16 to -17 ft		AB	H
-17 to -18 ft		78 dw	7.32
-18 to -20 ft		CB	69.7 dw
(berthing depth)		6.07	BB
-20 to -21 ft		EB	4.13
-21 to -22 ft		9.1 dw	DB
-22 to -23 ft		GB	7.9
-23 to -24 ft		4U dw	FB
-24 to -25 ft		IB	4U dw
-25 to -26 ft		4U dw	HB
-26 to -27 ft		KB	IB
-26 to -27 ft			JB

Area 29 (RM 4.6-4.7 E)		
location ID:	683	684
mudline:	4.7	0.6
+5 to +4 ft		
+4 to +3 ft	A (0-45)	
+3 to +2 ft	B	
+2 to +1 ft	C	
+1 to 0 ft	D	
0 to -1 ft	E	A (0-45)
-1 to -2 ft	F	B
-2 to -3 ft		C
-3 to -4 ft		D
-4 to -5 ft		E
-5 to -6 ft		F
-6 to -7 ft		G
-7 to -8 ft		H

Area 30 & 31 (RM 4.7 W)		
location ID:	694	814
mudline:	8.5	1.0
+9 to +8 ft		
+8 to +7 ft	16	
+7 to +6 ft	2.7 dw	
+6 to +5 ft	0.43 U	
+5 to +4 ft	D	
+4 to +3 ft	4U dw	
+3 to +2 ft	F	
+2 to +1 ft		
+1 to 0 ft		A (0-45)
0 to -1 ft		6.71
-1 to -2 ft		4.5 dw
-2 to -3 ft		4U dw
-3 to -4 ft		

Areas 32-25 (RM 4.8 to 5.0 E)											
location ID:	698X	698Y	699X	699Y	699Z	701	702X	702Y	703X	703Y	703Z
mudline:	-1.0	-5.9	-3.2	-6.6	-4.7	3.4	6.0	6.5	1.5	-0.8	-0.7
+6 to +5 ft							A (0-45)	A (0-45)			
+5 to +4 ft							B	0.09			
+4 to +3 ft							C	0.2 U			
+3 to +2 ft						A (0-45)	D	D			
+2 to +1 ft						40.4 dw		0.2 U			
+1 to 0 ft						4.5		F	PAHs <RALs		
0 to -1 ft						D			B		
-1 to -2 ft	A (0-45)					4U dw			C	A (0-45)	A (0-45)
-2 to -3 ft	4 U dw					F			D	B	B
-3 to -4 ft	C		4U dw							C	C
-4 to -5 ft	D									D	D
-5 to -6 ft	E				A (0-45)					E	E
-6 to -7 ft	F	A (0-45)			B					F	F
-7 to -8 ft	G	B		A (0-45)	C					G	G
-8 to -9 ft	H	C		4U dw	D						
-9 to -10 ft		D			E						
-10 to -11 ft		E			F						
-11 to -12 ft		F			G						
-12 to -13 ft		G									

Legend

- No RAL exceedances
- Exceeds RAL
- Interval below RAL that exceeds surface sediment RAL
- Archive
- Native sediment (can be any color)

Appendix A – PDI Phase III Data Report for the LDW Upper Reach

Attachment A.4
Interpolation Methods for Delineating Areas with RAL Exceedances

Lower Duwamish Waterway Group

City of Seattle / King County / The Boeing Company

APPENDIX A – PDI PHASE III DATA REPORT FOR THE LDW UPPER REACH

ATTACHMENT A.4
UPDATED INTERPOLATION METHODS FOR DELINEATING AREAS WITH RAL EXCEEDANCES IN THE UPPER REACH OF THE LOWER DUWAMISH WATERWAY

For submittal to

U.S. Environmental Protection Agency
Seattle, WA

December 15, 2023

Prepared by:

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ABBREVIATIONS

AC	activated carbon
COC	contaminant of concern
DER	Data Evaluation Report
ENR	enhanced natural recovery
FNC	federal navigation channel
LDW	Lower Duwamish Waterway
OC	organic carbon
PCB	polychlorinated biphenyl
PDI	pre-design investigation
RAA	remedial action area
RAL	remedial action level
RC	Recovery Category
RD	remedial design
RM	river mile

1 Introduction

This technical memorandum presents updated Phase III interpolation methods and results for delineating remedial action level (RAL) exceedances for polychlorinated biphenyls (PCBs) and other contaminants of concern (COCs) to support the 90% remedial design (RD) effort in the upper reach of the Lower Duwamish Waterway (LDW). Three phases of interpolation have been performed as new information has been obtained during three successive pre-design investigations (PDIs): Phase I, Phase II, and Phase III investigations. The updated interpolation results presented herein are supported by the full design dataset, incorporating Phase III data as well as data from all prior investigations. This memorandum builds on the Phase II interpolation work presented in the *Pre-Design Investigation Data Evaluation Report for the Lower Duwamish Waterway Upper Reach* (hereinafter referred to as the data evaluation report [DER]), specifically Appendix K, *Interpolation Methods for Delineating Areas with RAL Exceedances* (Anchor QEA and Windward 2022a).[1]

Subsequent to the DER, a detailed cross-validation analysis of Phase II indicator kriging results was performed to further assess the uncertainty associated with the RAL exceedance area boundaries, as presented in the *Draft Cross-Validation Analysis of Indicator Kriging in the Upper Reach of the Lower Duwamish Waterway* (Anchor QEA and Windward 2022b). This analysis was used to help inform the placement of additional surface and subsurface sediment sampling locations to refine RAL exceedance area boundaries and reduce interpolation uncertainty in specific areas, as described in the *Quality Assurance Project Plan Addendum for the Lower Duwamish Waterway Upper Reach: Pre-Design Investigation Phase III* (Windward and Anchor QEA 2022).

Indicator kriging was selected as the interpolation method to delineate the RAL boundary for PCBs, which account for the majority of the RAL exceedance area footprint in the upper reach. As summarized in the DER (Anchor QEA and Windward 2022a), indicator kriging requires characterization of spatial correlation structures through semivariogram analysis; it provides direct, quantitative estimates of the uncertainty of RAL exceedance area boundaries. Other COCs with RAL exceedances not co-located with PCB exceedances were addressed separately using a simpler interpolation method (Thiessen polygons), due to their more localized areas of concern and data densities that are not conducive to kriging (Anchor QEA and Windward 2022a).

This technical memorandum incorporates Phase III PDI chemistry data into the design dataset to develop updated RAL exceedance area boundaries for use in 90% RD. The following information is presented herein:

- Updated indicator kriging semivariograms for PCBs, incorporating Phase III data
- Comparisons of isotropic and anisotropic indicator kriging methods

[1] Appendix K of the DER provides an analysis of the statistical characteristics of the RD dataset, spatial correlation structures, interpolation method evaluation and selection, RAL exceedance area maps, and an uncertainty analysis.

- Indicator kriging interpolation maps for PCBs in surface sediment, subsurface sediment, and combined surface and subsurface sediment
- Comparisons of Phase II and Phase III PCB interpolations
- Updated Thiessen polygons for other COCs

1.1 Site Description

The upper reach of the LDW is composed of the following segments:

- **Lower Segment:** River mile (RM) 3.00 to RM 3.58, with a channel alignment of 312 degrees
- **Middle Segment:** RM 3.58 to RM 4.61, with a channel alignment of 348 degrees
- **Slip 6:** RM 4.18 to RM 4.27, an off-channel slip approximately perpendicular to the main channel
- **Turning Basin:** RM 4.61 to RM 5.00, which includes the Norfolk area (RM 4.80 to RM 5.00) on the upper east side of the waterway

Spatial interpolations were performed for the entire upper reach. Segment-specific interpolations were also performed in the middle and lower segments, which exhibit more consistent channel morphologies and flow directions, and thus more uniform hydrodynamic and sedimentary conditions. Interpolations were generally improved (i.e., longer and better-defined correlation structures) by segregating and focusing on those particular subsets of data.

Interpolations were performed separately on surface and subsurface depth intervals, which are defined in the LDW Record of Decision (EPA 2014) as:

- **Surface sediment**: 0 to 10 cm below mudline
- **Subsurface sediment**: 0 to 45 cm (intertidal areas), 0 to 60 cm (subtidal areas), and shoaling intervals in the Federal Navigation Channel (FNC)

Different PCB RALs apply in different areas and depths of the upper reach (EPA 2014):

- **Surface sediment:** RAL=12 mg/kg organic carbon (OC) applies to all surface sediment
- **Subsurface sediment:**
  - RAL=12 mg/kg OC applies to subsurface areas with a lower potential for natural recovery (Recovery Category [RC] 1) and shoaling intervals in the FNC.
  - RAL=65 mg/kg OC applies to subsurface sediment in intertidal areas in RC 2 and 3 areas.
  - RAL=195 mg/kg OC applies to subtidal sediment in potential vessel scour areas in RC 2 and 3 areas. Note that there are no exceedances in RAL=195 mg/kg OC areas in the upper reach; therefore, interpolations were not performed for RAL=195 mg/kg OC.
  - In any areas subject to the application of more than one RAL, the more stringent RAL was applied.

1.2 Phase III Data

Design dataset sampling locations (including those for Phase III data) in surface and subsurface sediments are shown on Maps A.4-1a through A.4-1c and Maps A.4-2a through A.4-2c, respectively. The Phase III sampling locations are highlighted to show where the new data were collected. These maps also show: 1) RAL exceedances and non-exceedances in the design dataset, 2) the previously interpolated Phase II RAL exceedance area boundary, and 3) the previous 60% RD remedial action area (RAA) boundary. Many of the Phase III samples were specifically collected to reduce the uncertainty of RAL exceedance area boundaries in particular areas (Windward and Anchor QEA 2022).

Design dataset sample counts (including Phase III data) are compiled in Table A.4.1-1 for surface sediments and subsurface sediments in each of the RAL application areas and upper reach segments. In surface sediments, there was only a nominal (2%) increase in the upper reach sample count due to the addition of Phase III data (only 17 out of 776 surface sediment samples are Phase III data). In subsurface sediments, there was a more significant (12%) increase in the upper reach sample count due to the addition of Phase III data (46 out of 377 subsurface sediment samples are Phase III data).

Table A.4.1-1
PCB Sample Counts and RAL Exceedance Frequencies – Design Dataset Including Phase III Data

Upper Reach Segment	Surface Sediment		Subsurface Sediment							
	RAL = 12		RAL = 12		RAL = 65		RAL = 195		Total Subsurface	
	Exceedance Count	Exceedance Percent	Exceedance Count	Exceedance Percent	Exceedance Count	Exceedance Percent	Exceedance Count	Exceedance Percent	Exceedance Count	Exceedance Percent
Lower	8/176	5%	36/89	40%	0/17	0%	0/32	0%	36/138	26%
Middle	42/410	10%	10/82	12%	20/99	20%	0/11	0%	30/192	16%
Slip 6	0/48	0%	2/11	18%	0/0	NA	0/4	0%	2/15	13%
Upper Turning Basin	16/142	11%	2/8	25%	0/22	0%	0/2	0%	2/32	6%
All Segments	66/776	9%	50/190	26%	20/138	14%	0/49	0%	70/377	19%

Notes:
NA: not applicable
PCB: polychlorinated biphenyl
RAL: remedial action level

2 Phase III Semivariograms

Phase III spatial correlation structures, as determined through semivariogram analysis, are presented in this section. Phase III correlation structures are supported by the full design dataset, including Phase III data and data from all previous investigations. Phase III surface sediment and subsurface sediment semivariogram plots and spatial correlation models are compiled in Figure A.4.2-1. Phase III surface sediment and subsurface sediment spatial correlation parameters (e.g., model type, anisotropy [if used], sill, nugget, and range values) are compiled in Table A.4.2-1.

Table A.4.2-1
Phase III Surface Sediment and Subsurface Sediment Spatial Correlation Parameters

Depth:	Surface Sediment		Subsurface Sediment					
RAL:	RAL = 12		RAL = 12				RAL = 65	
Segment:	Full Reach	Middle Segment	Full Reach	Full Reach	Middle Segment	Lower Segment	Full Reach	Middle (Intertidal)
Sample Count	768	401	375	375	191	137	375	113
Variogram Parameters								
Model type	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
Model directionality	Isotropic	Isotropic	Isotropic	Anisotropic	Anisotropic	Anisotropic	Isotropic	Anisotropic
Directional azimuth	--	--	--	332°	345°	314°	--	345°
Nugget	0.020	0.02	0.05	0.05	0.06	0.05	0.02	0.03
Nugget (% of Full Sill)	17%	18%	24%	24%	30%	22%	25%	13%
Partial sill	0.095	0.09	0.16	0.16	0.14	0.18	0.06	0.20
Full sill	0.115	0.11	0.21	0.21	0.20	0.23	0.08	0.23
Major range (feet)	30	45	40	60	120	80	40	60
Minor range (feet)	--	--	--	30	40	40	--	30
Anisotropy ratio	NA	NA	NA	2-to-1	3-to-1	2-to-1	NA	2-to-1
Search Parameters								
Search sector type	Quadrant/45°	Quadrant/45°	Quadrant/45°	Quadrant/45°	Quadrant/45°	Quadrant/45°	Quadrant/45°	Quadrant/45°
Max neighbors to include	5	5	5	5	5	5	5	5
Min neighbors to include	2	2	2	2	2	2	2	2
Major search radius (feet)	100	100	150	200	300	200	150	200
Minor search radius (feet)	--	--	--	100	100	100	--	100

Notes:
NA: not applicable
RAL: remedial action level

2.1 Surface Sediment Semivariograms

Because there was only a 2% increase in the number of surface sediment samples with the addition of Phase III data, the Phase III surface sediment semivariograms are practically the same as the Phase II semivariograms.

2.2 Subsurface Sediment Semivariograms

Because there was a significant increase (12%) in the subsurface sediment dataset with the addition of Phase III data, a re-analysis of the Phase III subsurface sediment semivariograms was warranted, and spatial correlation structures were refined and improved. Consistent with the Phase II approach, segment-specific models were developed for the middle and lower segments, while full-reach models were applied to Slip 6 and the Turning Basin because of the more variable channel and flow geometries in these areas. The spatial correlation structure for the RAL=65 mg/kg OC analysis in the middle segment was developed using only intertidal samples from RC 2 and 3 areas, because those are the only samples in this segment for which RAL=65 is applicable.

Model Directionality. The main update to the subsurface semivariograms pertains to model directionality. The addition of Phase III data to the design dataset allowed for the resolution of directional anisotropy in the middle and lower segments, which expanded the correlation range along the direction of flow. Anisotropic correlation structures are common and expected in long, narrow waterways like the LDW, with prevailing directions of river currents and tides. Anisotropic semivariograms require development of spatial correlation structures in both the longitudinal (along-flow) and transverse (cross-flow) directions. The correlation range of an anisotropic model varies with the compass direction, while the nugget and sill values remain constant. Nondirectional, isotropic models continued to be applied to Slip 6 and the Turning Basin, which have more variable channel and flow geometries.

Range Values. In the middle and lower segments, which supported the development of anisotropic semivariograms, longer correlation scales were observed in the longitudinal direction than in the transverse direction. Phase II subsurface correlation scales using isotropic models ranged from 50 to 75 ft. Phase III anisotropic correlation scales ranged from 70 to 120 ft in the longitudinal direction and from 35 to 40 ft in the transverse direction. The anisotropy ratios (longitudinal range/transverse range) in the middle and lower segments ranged between 2-to-1 and 3-to-1.

Nugget Values. Nugget values were relatively well controlled, ranging from 13% to 29% of their respective sill values.

Sill Values. Compared to surface sediment, higher sill values were typically observed in subsurface sediment, especially in RC 1 areas where the subsurface RAL is 12 mg/kg OC, because of the greater percentage of PCB RAL exceedances in subsurface sediment and, as a result, greater population variances of the indicator variables.

2.3 Isotropic versus Anisotropic Method Comparison

With the addition of Phase III data, anisotropic correlation structures became more evident in subsurface sediments in the middle and lower segments. Using anisotropic correlation structures, interpolated sediment deposits with RAL exceedances are more elongated in the flow direction (i.e., parallel to the shoreline and bathymetry contours).

The use of anisotropic correlation structures is preferred to the use of isotropic correlation structures in LDW, because anisotropic correlation structures:

- Provide a longer correlation scale along the prevailing flow and tidal direction
- Are more consistent with the conceptual model of riverine/estuarine hydrodynamics and sedimentary processes in long, narrow waterways such as LDW
- Have been successfully applied at other sediment cleanup sites, including the Lower Fox River and the Hudson River (Kern et al. 2008; QEA 2007)

For example, the two areas shown on Map A.4-3a (the RC 1 area in the lower segment between RM 3.0 and RM 3.3) and Map A.4-3b (the middle segment near RM 4.1 East) illustrate the differences in interpolation results using isotropic (non-directional) versus anisotropic (directional) semivariograms.

The proposed use of anisotropic correlation structures in subsurface sediments was discussed with EPA during a teleconference on March 2, 2023. EPA (Michael Beuthe) subsequently approved the use of anisotropic correlation structures in an email communication on March 15, 2023.

3 Phase III Interpolation Results

Spatial correlation parameters, as determined through semivariogram analysis, and kriging search parameters are compiled in Table A.4.2-1. Kriging interpolation methods (i.e., isotropic versus anisotropic) and segmentation schemes (i.e. site-wide versus segment specific) are summarized in Table A.4.3-1.

Table A.4.3-1
Upper Reach Interpolation Methods and Segmentation

Upper Reach Area		Phase II		Phase III		Phase II/III
		Indicator Kriging: Site-wide	Indicator Kriging: Segment-specific	Indicator Kriging: Site-wide	Indicator Kriging: Segment-specific	Thiessen Polygons
Surface Sediment						
PCBs	Lower segment (RM 3.00–RM 3.58)	I		I		
PCBs	Middle segment (RM 3.58–RM 4.61)		I		I	
PCBs	Slip 6 (RM 4.18–RM 4.27)	No RAL exceedances				
PCBs	Turning Basin area (RM 44.61–RM 4.80)	I		I		
PCBs	Norfolk area (RM 4.80–RM 5.00)	I		I		
Other COCs – All Areas						X
Subsurface Sediment						
PCBs	Lower segment (RM 3.00–RM 3.58)		I		A[1]	
PCBs	Middle segment (RM 3.58–RM 4.61)		I		A[2]	
PCBs	Slip 6 (RM 4.18–RM 4.27)	I		I[3]		
PCBs	Turning Basin area (RM 4.61–RM 4.80)	I		I[4]		
PCBs	Norfolk area (RM 4.80–RM 5.00)	No RAL exceedances				
Other COCs – All Areas						X

Notes:
1. Includes anisotropic correlation structure for RAL=12 mg/kg OC
2. Includes anisotropic correlation structures for RAL=12 and RAL=65 mg/kg OC
3. Includes isotropic correlation structure for RAL=12 mg/kg OC
4. Includes isotropic correlation structures for RAL=12 and RAL=65 mg/kg OC

A: Anisotropic correlation structure
COC: contaminant of concern
I: Isotropic correlation structure
OC: organic carbon
PCB: polychlorinated biphenyl
RAL: remedial action level
RM: river mile

Indicator kriging provides point-based estimates of the probability of exceeding the RAL. Samples that exceed the RAL are assigned a probability value of 1 (100%), and samples that do not exceed the RAL are assigned a probability value of 0 (0%). Indicator kriging then interpolates the field of indicator values represented by zeroes and ones. Between sample locations, the indicator is a continuous variable spanning a range of values between 0 and 1 (i.e., 0% to 100% probability of exceedance), which is estimated by the kriging algorithm based on the correlation structure and spatial distribution of the data. Indicator kriging was performed using the Esri ArcGIS program (ArcGIS Desktop 10.8.1 and Geostatistical Analyst 10.8.1 extension).

Indicator kriging interpolation results are provided in the following map sets:

- **Maps A.4-4a, A.4-4b, A.4-4c** provide surface sediment interpolation for the lower, middle, and upper segments of the upper reach, respectively.
- **Maps A.4-5a, A.4-5b, A.4-5c** provide subsurface sediment interpolation for the lower, middle, and upper segments of the upper reach, respectively.
- **Maps A.4-6a, A.4-6b, A.4-6c** provide combined surface and subsurface sediment interpolation for the lower, middle, and upper segments of the upper reach, respectively. This map set also includes the updated 90% RD RAA boundary and toe of the dredge cut, which incorporate any 90% RD revisions needed to address Phase III data.

The indicator kriging contours on these maps represent the probabilities of exceeding the applicable RALs, expressed in units of percent. The 50% (median) probability of exceedance contour represents the median estimate of the horizontal RAL exceedance boundary. Other contours are also provided for comparison, including the 20%, 30%, 40%, 60%, 70%, and 80% probabilities of exceedance.

3.1 Phase III Surface Sediment Interpolation

Updated surface sediment interpolations including Phase III PDI data are provided in Maps A.4-4a through A.4-4c. The Phase III surface sediment results helped refine the RAL exceedance area boundaries. Nearly all of the surface sediment results from the Phase III investigation (16 out of 17 samples, or 94%) do not exceed the RAL. There was only one Phase III RAL exceedance in surface sediment, located in the intertidal area near RM 3.7 West (Maps A.4-1b and A.4-4b). This surface sediment sample had a relatively low exceedance ratio of 1.3 times the RAL.

3.2 Phase III Subsurface Sediment Interpolation

Updated subsurface sediment interpolations including Phase III PDI data are provided in Maps A.4-5a through A.4-5c. The Phase III subsurface sediment results helped refine the RAL exceedance area boundaries. A majority of the subsurface sediment results from the Phase III investigation (33 out of 46 samples, or 72%) are less than the RAL.

There are several areas where Phase III PCB RAL exceedances were observed in subsurface sediments outside of previously developed RAL exceedance areas during 60% RD, including the following:

- **Lower Segment**: RM 3.0 to RM 3.2 West (RC 1 area along the lower west slope)
- **Lower-Middle Transition**: RM 3.6 West (offshore of Terminal 117 along lower west slope)
- **Middle Segment**: RM 3.8 West (expansion of a small intertidal deposit); RM 3.8 to RM 4.0 East (expanded RAL exceedance areas near the enhanced natural recovery/activated carbon [ENR/AC] pilot plots on the lower west slope and adjacent intertidal areas)

3.3 Phase III RAL Exceedance Area Boundaries

Using a GIS raster calculation, the surface and subsurface PCB indicator kriging maps were combined into a single map showing the total combined RAL exceedance area footprint of both layers. This map represents the highest indicator probability value in either surface or subsurface sediments at each location, as shown in Maps A.4-6a through A.4-6c. In some parts of the upper reach, the maximum extent of the RAL exceedance area boundary is defined by surface sediment exceedances; in other parts of the upper reach, it is defined by subsurface sediment exceedances.

The 50% probability contour, representing the median indicator value, was used as the starting basis for 90% RD (i.e., the same basis that was used in 30% and 60% RD). The 90% RD RAA boundaries and toe of cut in proposed dredging areas are shown on Maps A.4-6a through A.4-6c, along with the median probability boundary from both the Phase II and Phase III interpolations. These maps include areas where Phase III sampling results required modifications to RD, including expansions (based on Phase III exceedances) and contractions (based on Phase III non-exceedances) of the RAAs.

During the design process, the RAA footprint is expanded beyond the RAL exceedance area boundary in order to develop a constructible design and accommodate stable side slopes. As a result, the engineering design process imparts a greater level of confidence in the RD. Although the 50% probability contour is used as the starting basis for RD, the certainty in the final design is greater after incorporating constructability and side slope requirements, because the RAA boundary expands to intersect sediments with lower probabilities of exceedance, ranging from 40% to less than 20%.

3.4 Phase II versus Phase III RAL Exceedance Area Boundaries

Comparisons of Phase II and Phase III interpolation results are provided in Maps A.4-7a through A.4-7e, which present side-by-side panels of Phase II and Phase III interpolations and indicator probability contours. In the subsurface dataset, there has been some reshaping of the indicator probability contours as a result of the change from using isotropic to anisotropic correlation structures in the middle and lower segments. Compared to the Phase II RAL exceedance areas, the Phase III RAL exceedance areas in the middle and lower segments are more elongated along the axis of the waterway and parallel to the shoreline. The Phase III interpolation forms the basis for the 90% RD.

3.5 Updated Thiessen Polygons for Other COCs

Although PCB exceedances delineate the majority of contamination in the upper reach, the PCB RAL exceedance area boundaries were expanded in certain areas where other COCs exceeded RALs but PCBs did not. Because these areas are small and more localized, the RAL exceedance area boundaries for COCs other than PCBs were established using Thiessen polygons. Other COCs that locally determined a RAL exceedance area boundary included metals, polycyclic aromatic hydrocarbons, other semivolatile organic compounds (butyl benzyl phthalate, benzoic acid, and phenol), and dioxins/furans, depending on the area.

A comparison of Thiessen polygons based on the Phase II and Phase III design datasets is shown in the left and right frames, respectively, on Maps A.4-8a through A.4-8e. This map set shows the distribution of PCB RAL exceedance areas delineated by the median (50%) indicator kriging probability (pink areas), as well as Thiessen polygons for other COCs that extend beyond the PCB exceedance area boundaries (yellow).

In general, the changes to the Thiessen polygon boundaries are relatively minor. There are a few adjustments and expansions of polygon boundaries along the eastern slope and intertidal area near the ENR/AC pilot plots (between RM 3.7 East and RM 4.0 East), as well as a lost polygon at the western shore at RM 3.5 West, as a result of Phase III data. However, these changes are small.

4 Conclusions

This technical memorandum presents updated Phase III interpolation methods and results for delineating RAL exceedance areas for PCBs and other COCs to support the 90% RD in the upper reach of the LDW. The main results and conclusions of the Phase III interpolation update include the following:

- In surface sediments, there was only a nominal (2%) increase in the upper reach sample count due to the addition of Phase III data. As a result, the Phase II semivariograms were still valid to use to define surface sediment correlation structures. In subsurface sediments, there was a more significant (12%) increase in the sample count due to the addition of Phase III data. Therefore, the semivariograms for subsurface sediments were re-evaluated and correlation structures were improved in most cases.
- The addition of Phase III subsurface data allowed for the resolution of directional anisotropy in the middle and lower segments, thereby expanding the correlation range along the flow direction of river and tidal currents.

- One of the Phase III sampling objectives was to collect data in areas of greater uncertainty to help refine the indicator probability contours and increase the confidence of the RAL exceedance area boundaries in those areas. This Phase III sampling objective was achieved.
- In some of Phase III data collection areas, RAL exceedances were observed outside the 60% RD RAA and/or non-exceedances were observed inside the 60% RD RAA. The 90% RD uses the updated interpolation as its basis, including any refinements required by Phase III data prior to the addition of engineering considerations.
- There were only minor changes to the Thiessen polygon boundaries, which were used to delineate RAL exceedance areas for COCs other than PCBs.

5 References

Anchor QEA, Windward. 2022a. Pre-Design Investigation data evaluation report for the Lower Duwamish Waterway upper reach. Final. For submittal to US Environmental Protection Agency, July 15, 2022. Anchor QEA and Windward Environmental LLC, Seattle, WA.

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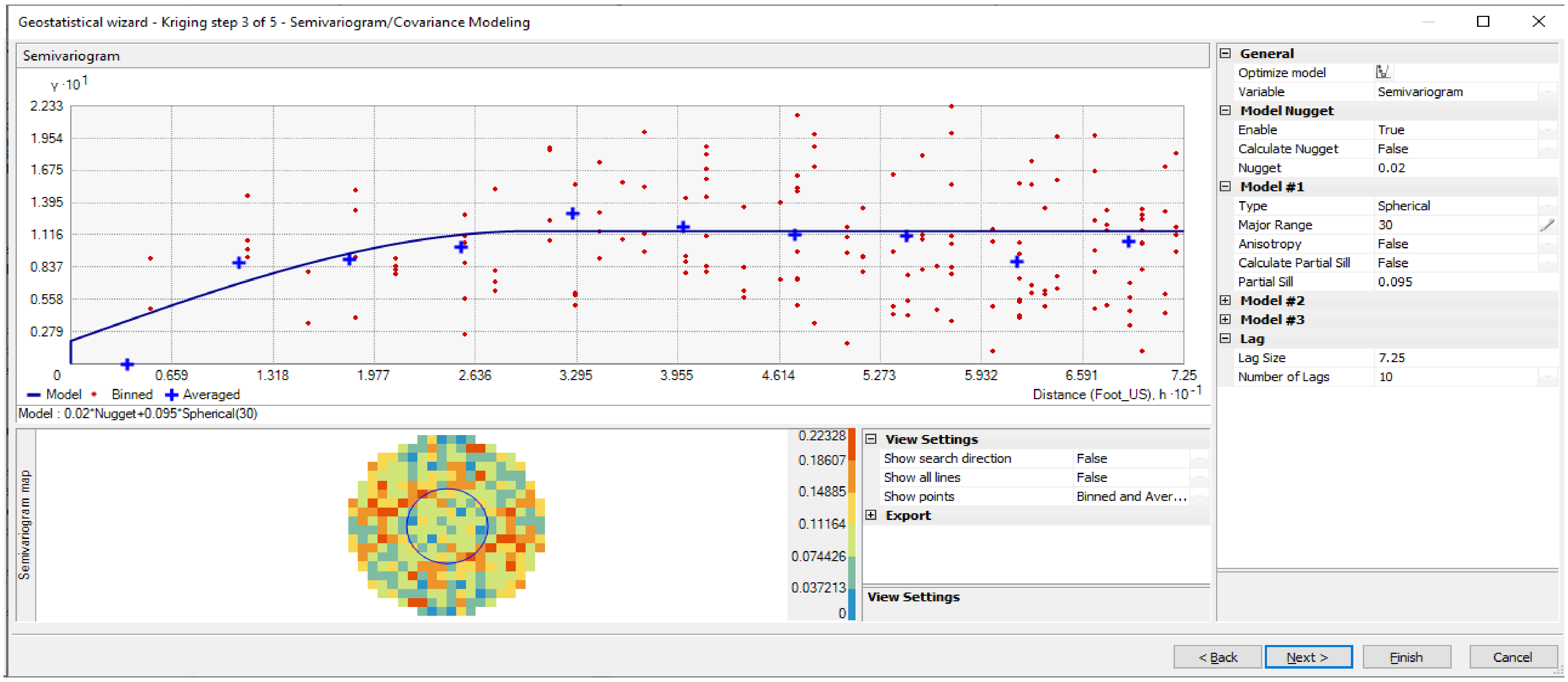
Figures

Figure A.4.2-1
Phase III surface sediment and subsurface sediment semivariogram plots andspatial correlation models

Surface - Full Reach - Isotropic



Surface - Middle Segment - Isotropic

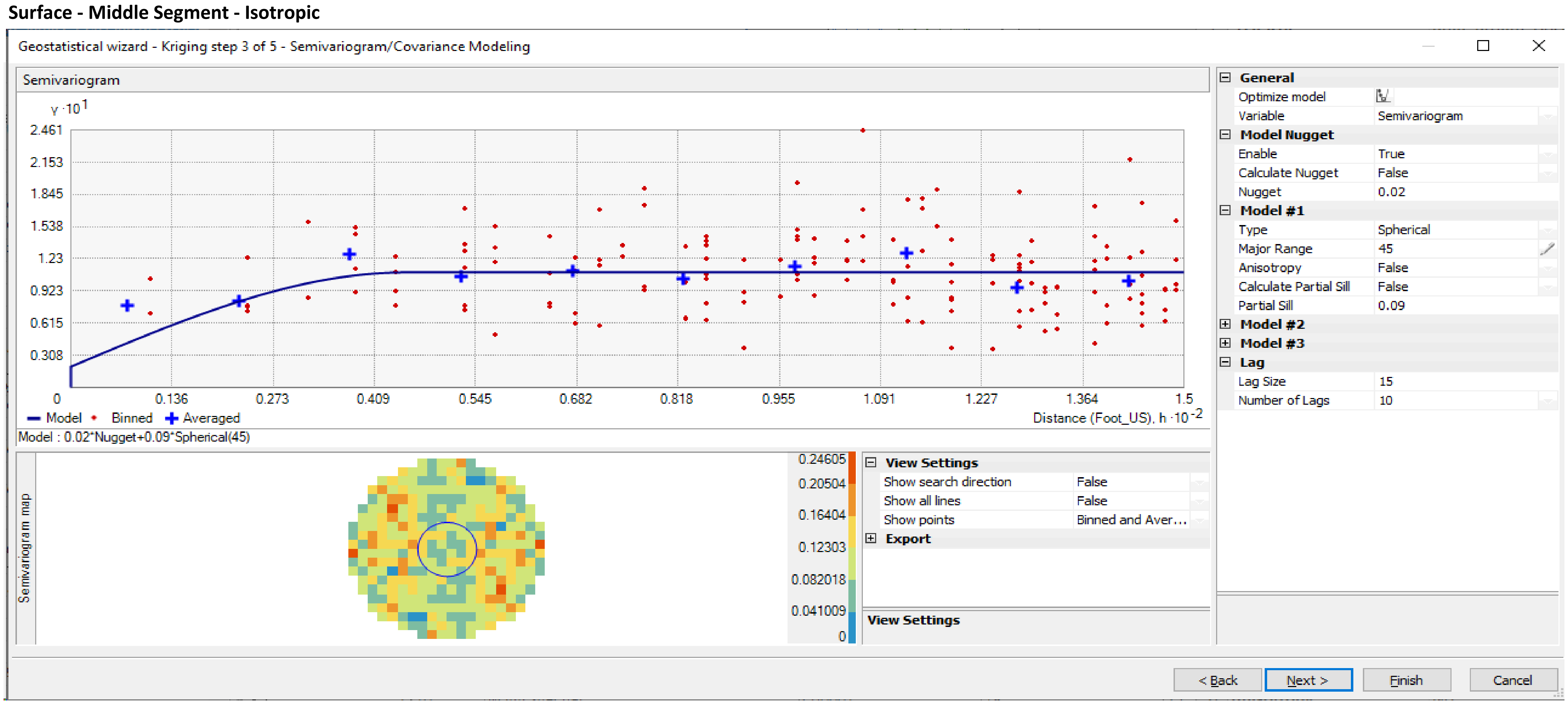


Figure A.4.2-1
Phase III surface sediment and subsurface sediment semivariogram plots andspatial correlation models

Subsurface RAL=12 - Full Reach - Isotropic

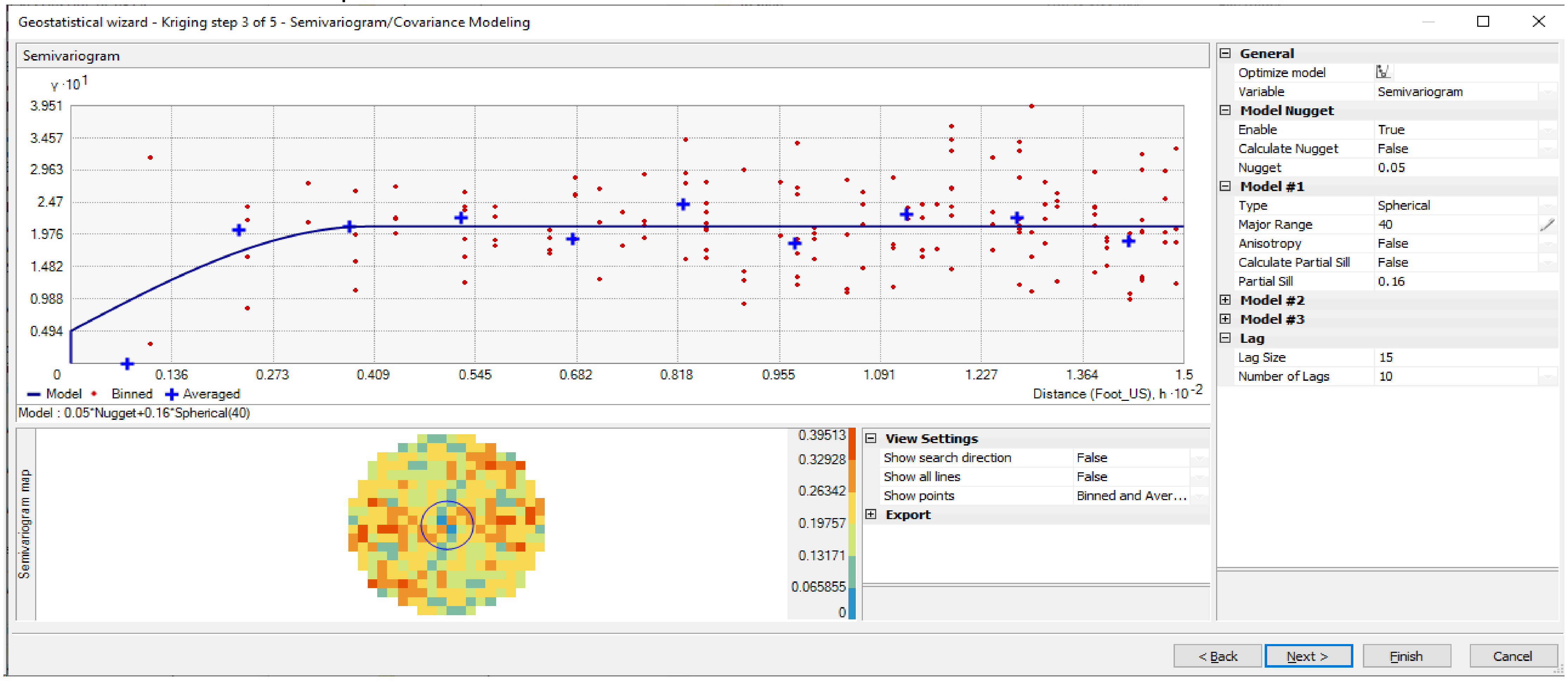
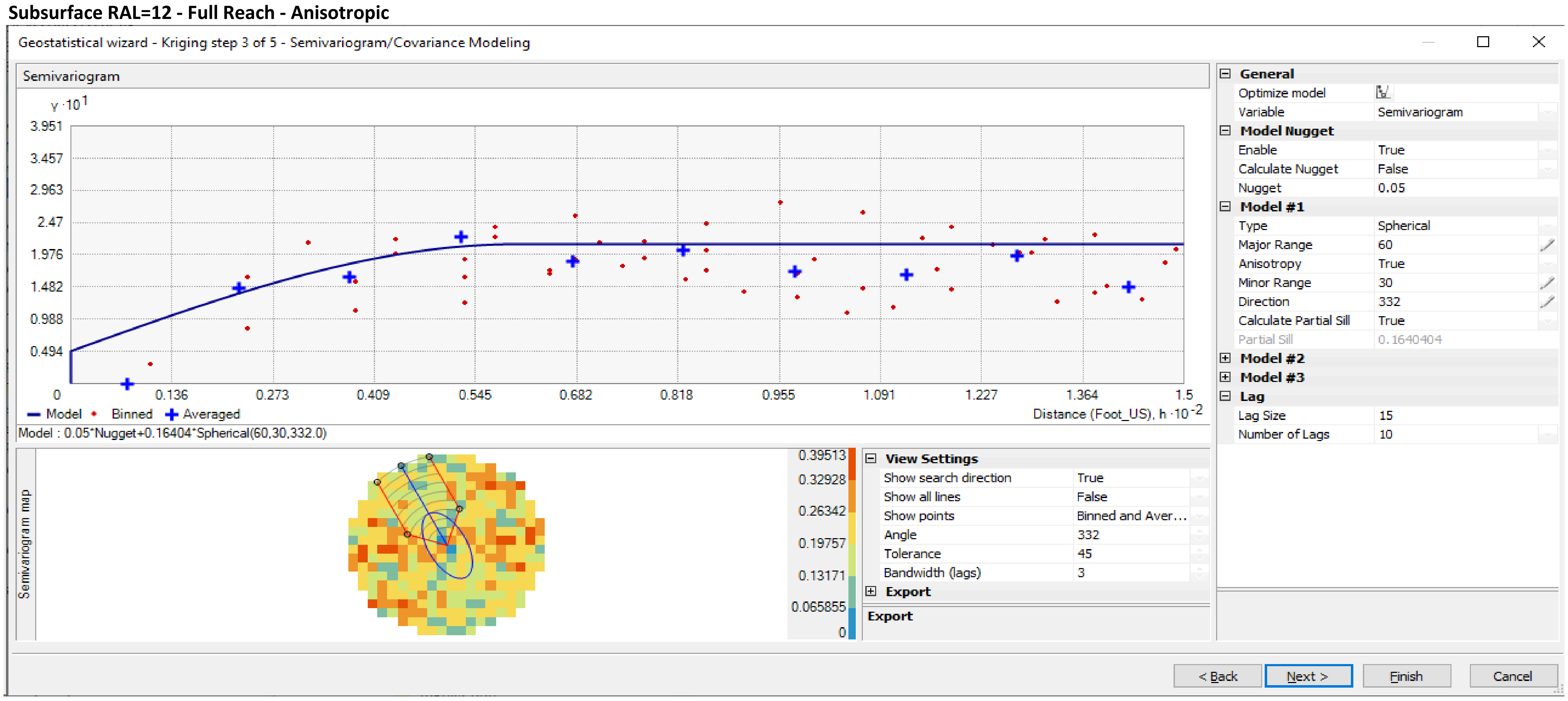


Figure A.4.2-1
Phase III surface sediment and subsurface sediment semivariogram plots andspatial correlation models

Subsurface RAL=12 - Full Reach - Anisotropic



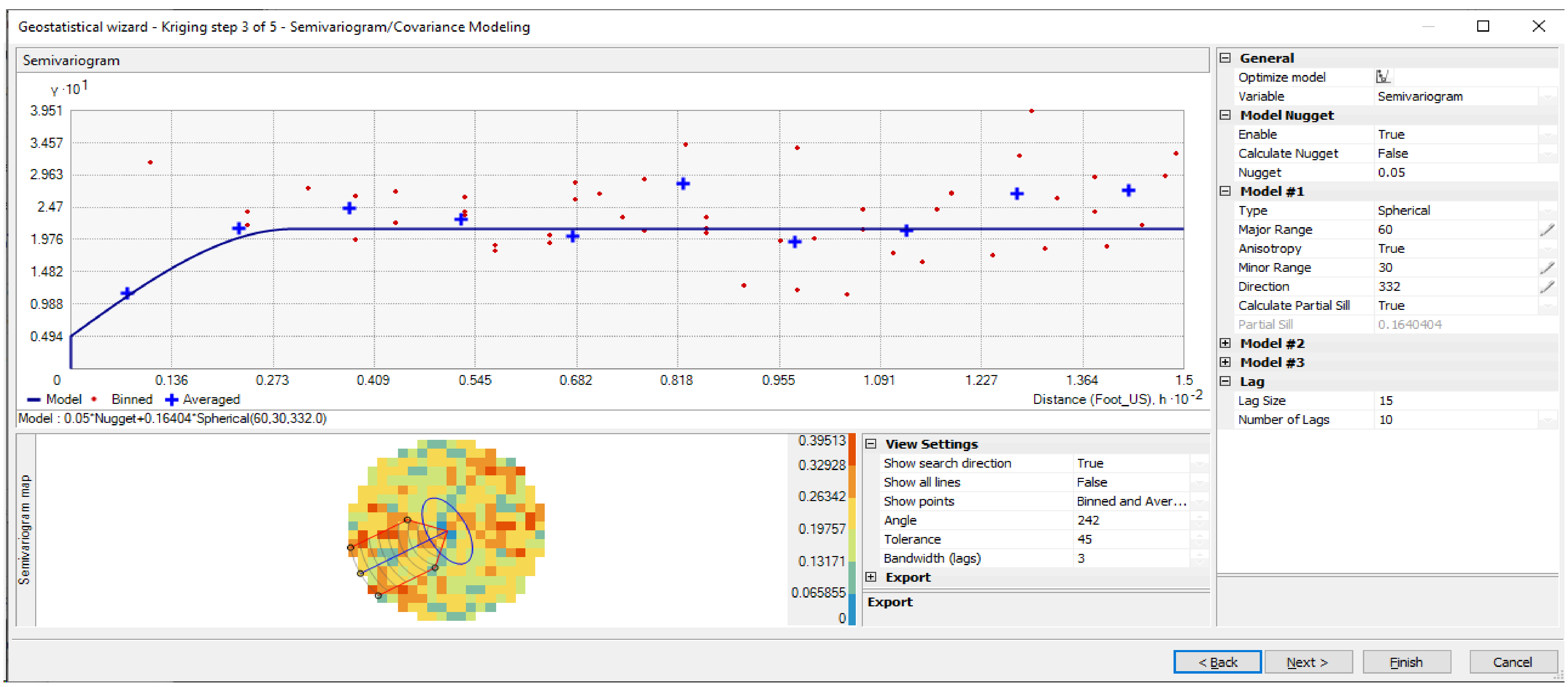


Figure A.4.2-1
Phase III surface sediment and subsurface sediment semivariogram plots andspatial correlation models

Subsurface RAL=12 - Lower Segment - Anisotropic

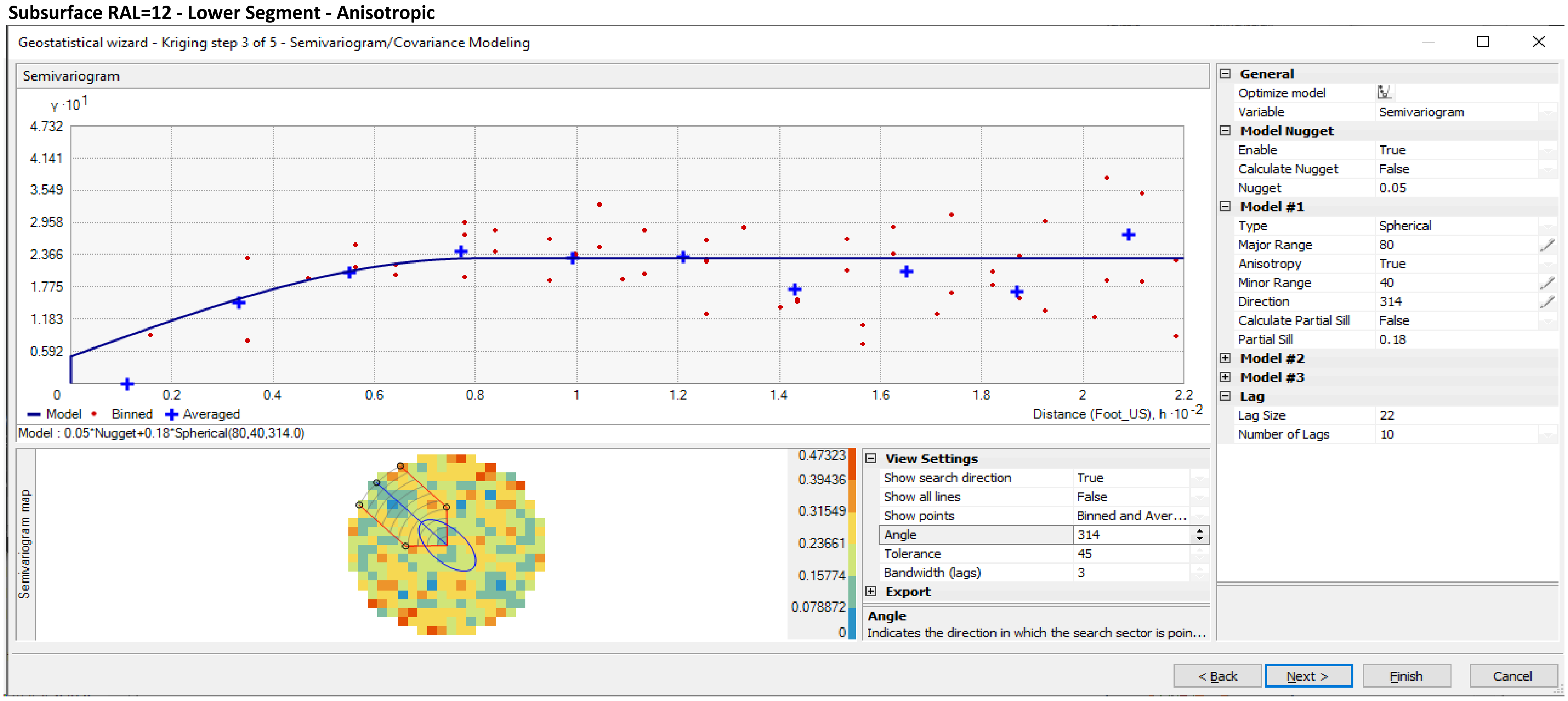
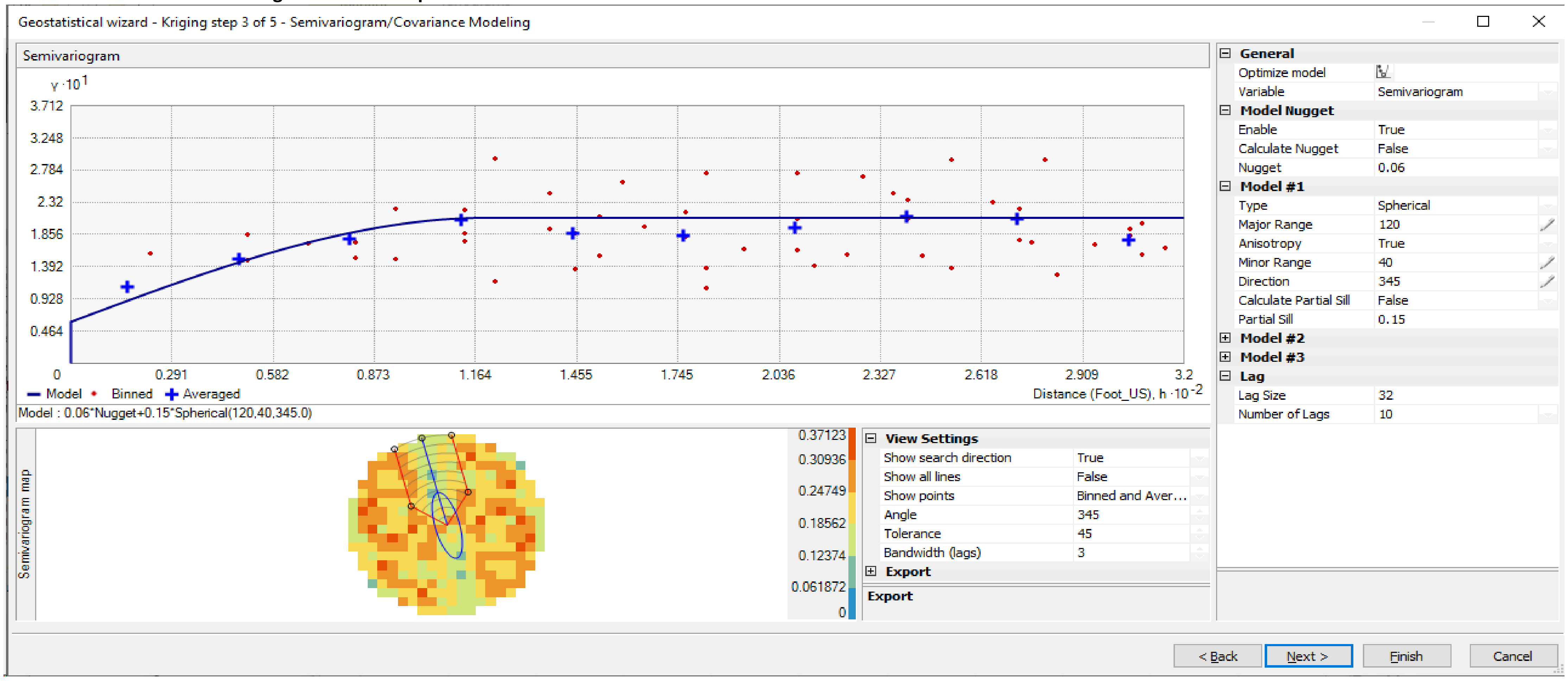


Figure A.4.2-1
Phase III surface sediment and subsurface sediment semivariogram plots andspatial correlation models

Subsurface RAL=12 - Middle Segment - Anisotropic



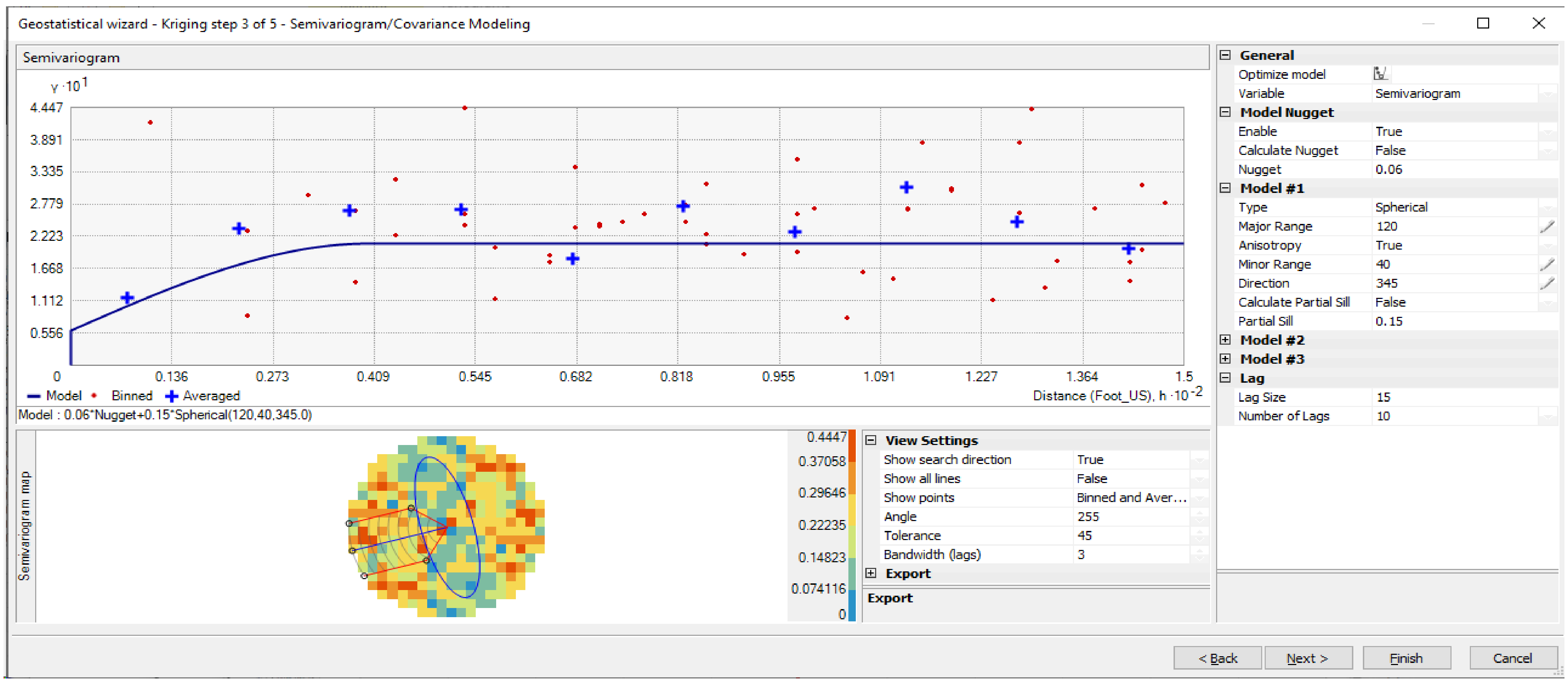


Figure A.4.2-1
Phase III surface sediment and subsurface sediment semivariogram plots andspatial correlation models

Subsurface RAL=65 - Full Reach - Isotropic

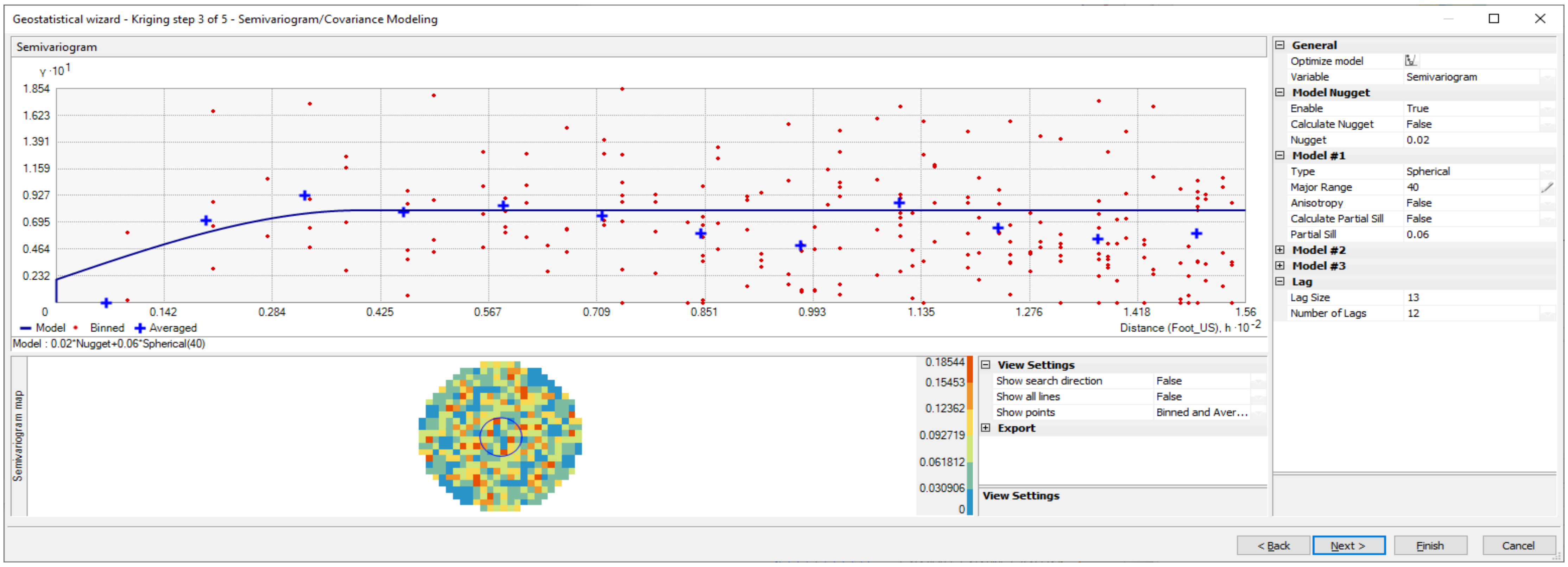
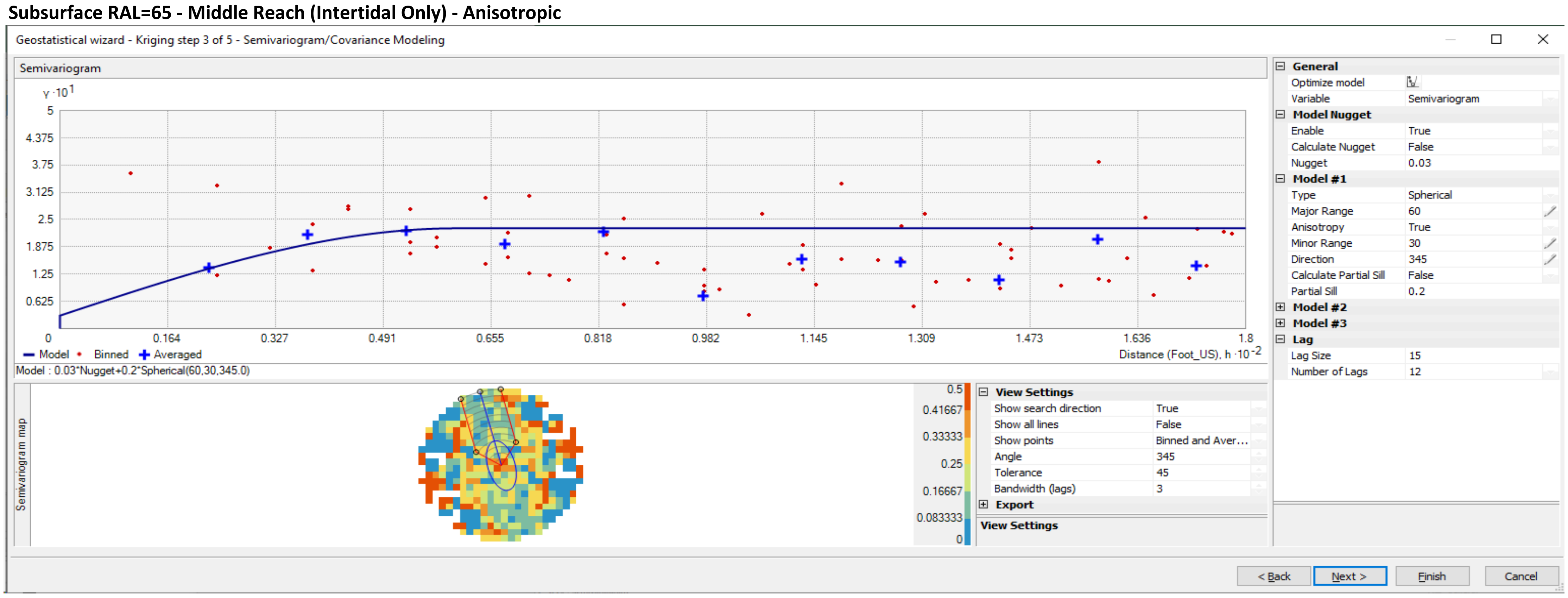
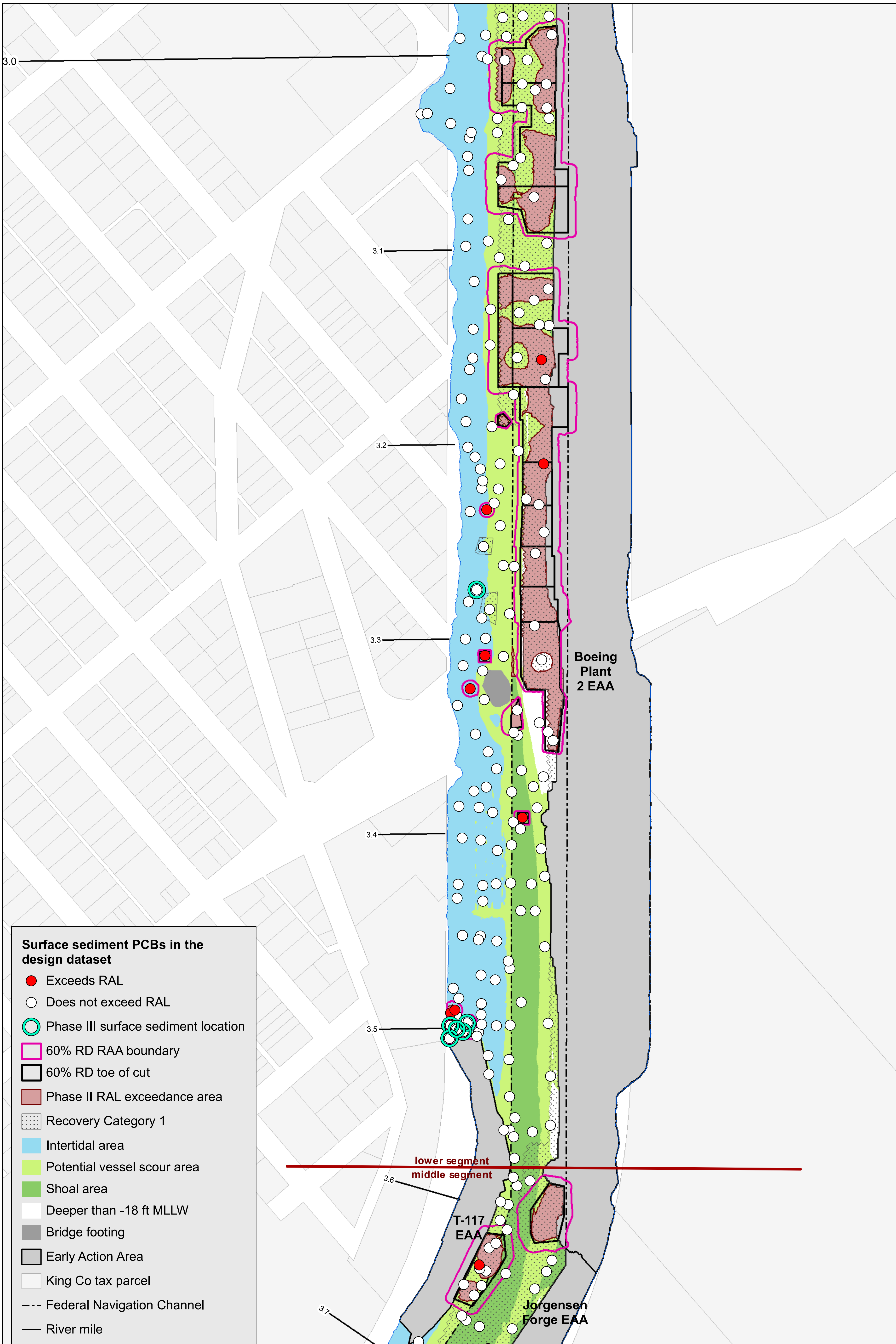


Figure A.4.2-1
Phase III surface sediment and subsurface sediment semivariogram plots andspatial correlation models

Subsurface RAL=65 - Middle Reach (Intertidal Only) - Anisotropic



Maps



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N

0 200 400 Feet
0 40 80 Meters

Map A.4-1a. Design dataset surface sample locations, including Phase III data, RM 3.0 to RM 3.7

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Prepared by craigh, 10/24/23; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Remedial Design\App A Phase III Data Report\Att 4 Interpolation Update\Map A4-1a 7503 PhIII grabs - 1.mxd

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N

0 200 400 Feet

0 40 80 Meters

Map A.4-1b. Design dataset surface sample locations, including Phase III data, RM 3.7 to RM 4.3

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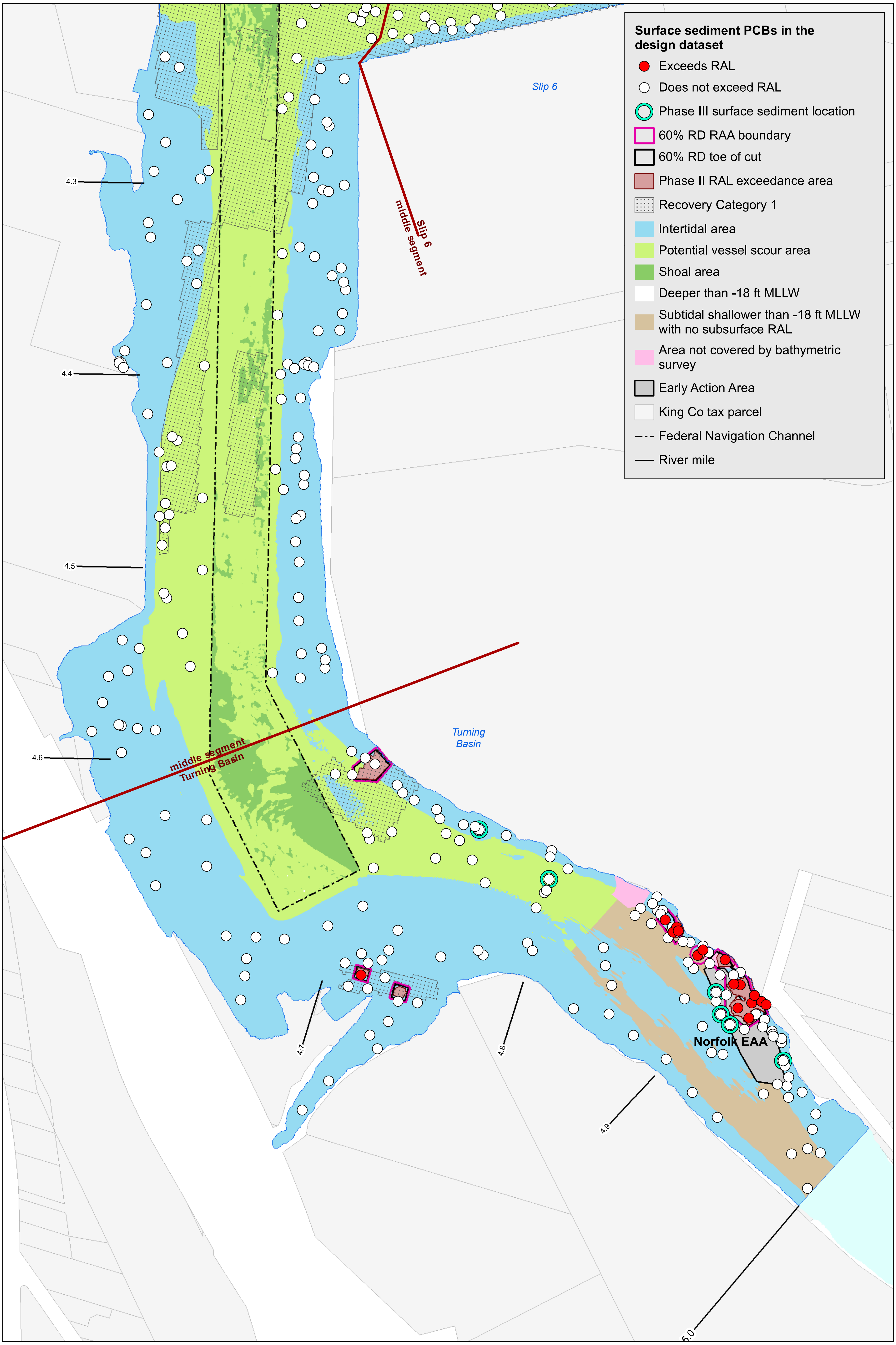

N

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0 40 80 Meters

Map A.4-1c. Design dataset surface sample locations, including Phase III data, RM 4.3 to RM 5.0

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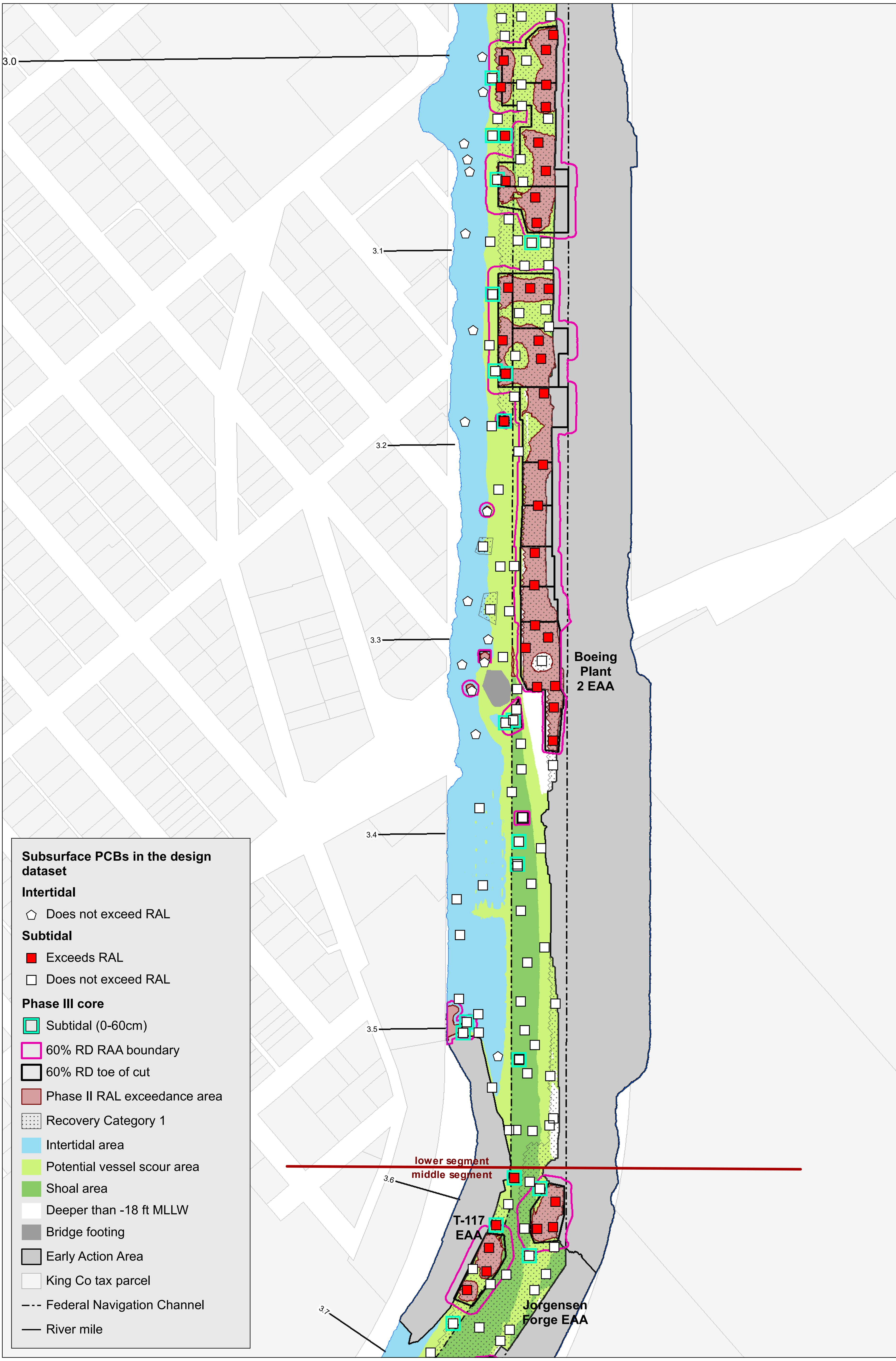

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0 200 400 Feet
0 40 80 Meters

Map A.4-2a. Design dataset subsurface sample locations, including Phase III data, RM 3.0 to RM 3.7

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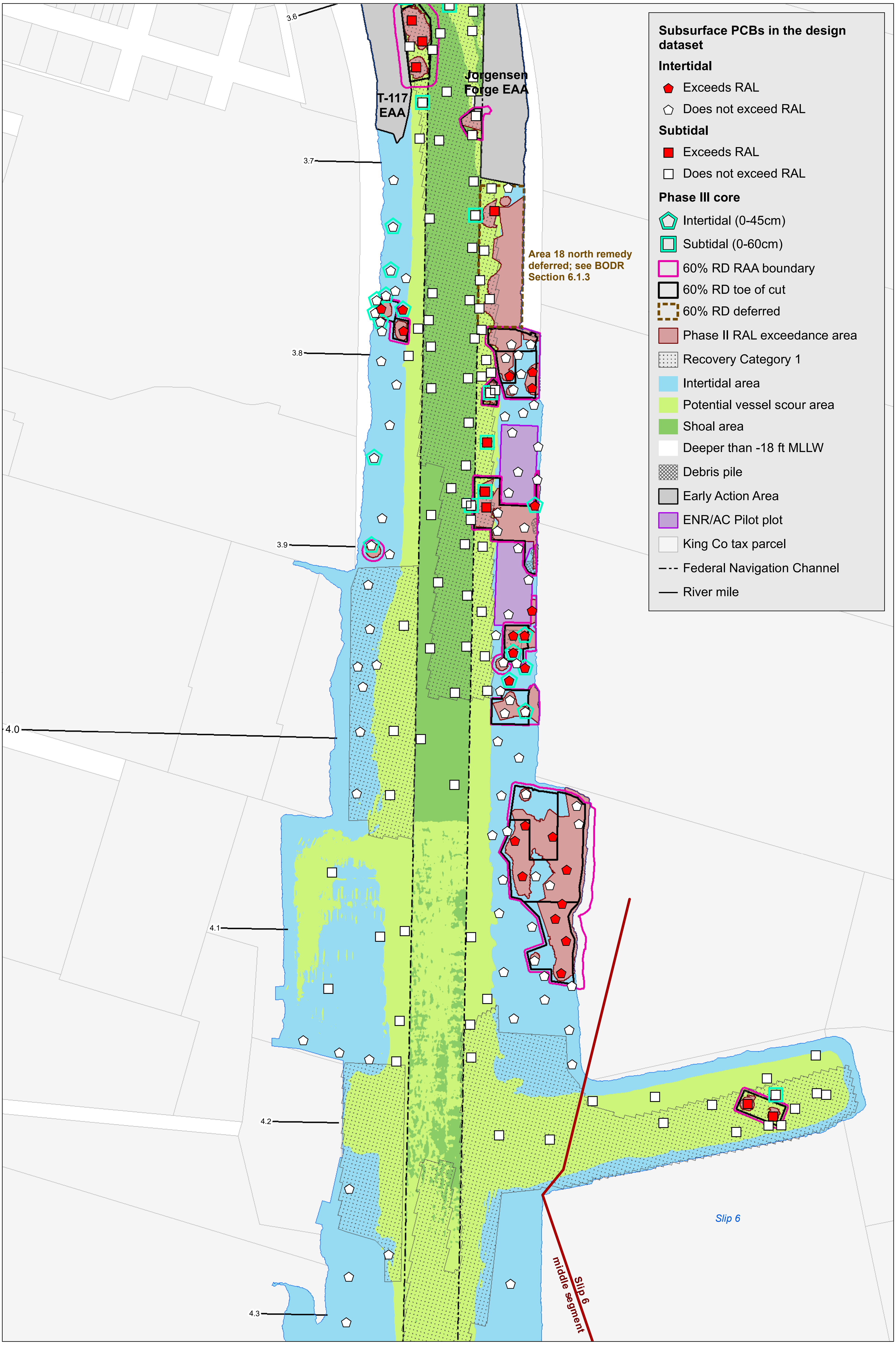

N

0 200 400 Feet

0 40 80 Meters

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Map A.4-2b. Design dataset subsurface sample locations, including Phase III data, RM 3.7 to RM 4.3

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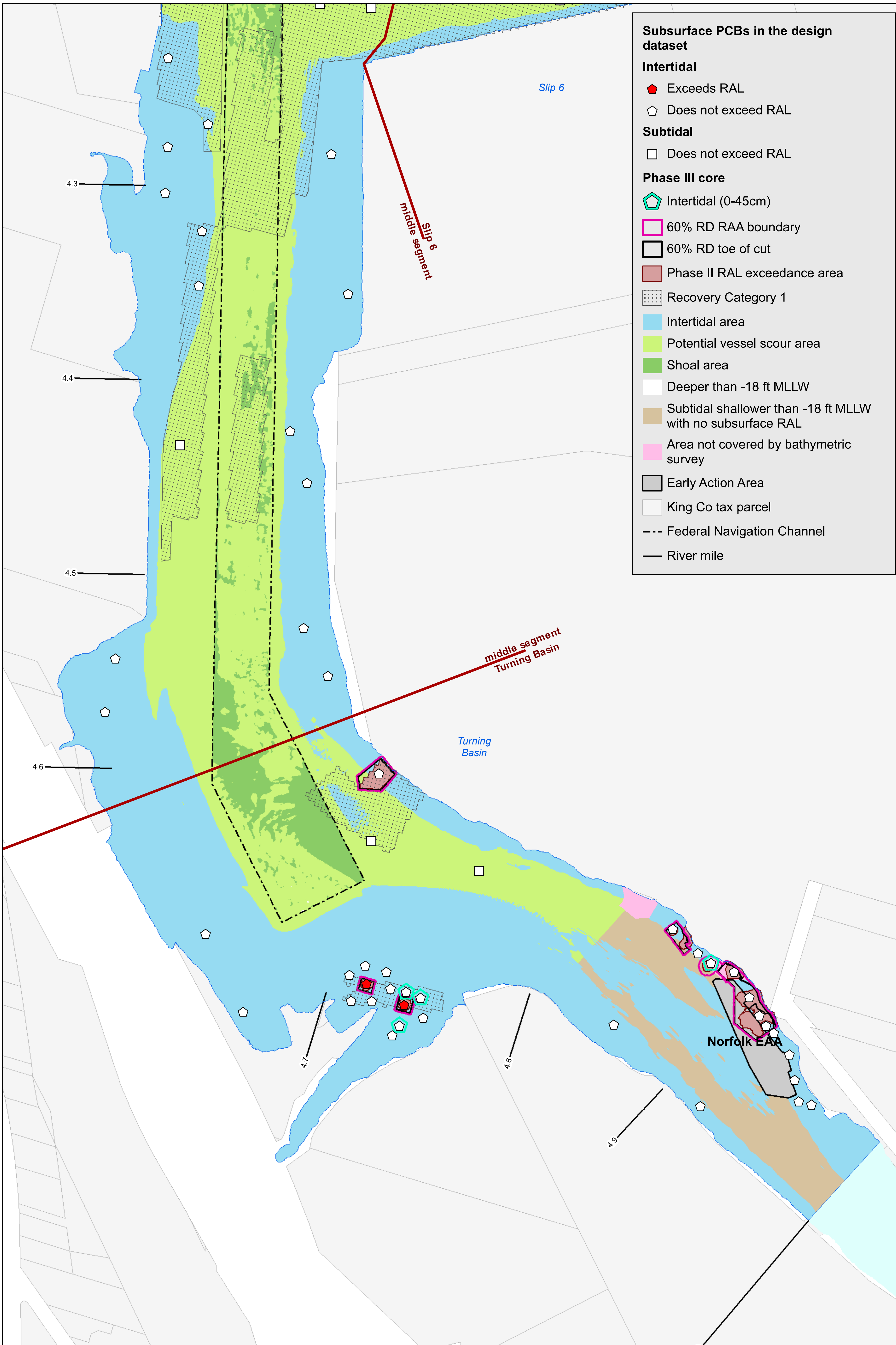

N
0 200 400 Feet
0 40 80 Meters

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Map A.4-2c. Design dataset subsurface sample locations, including Phase III data, RM 4.3 to RM 5.0

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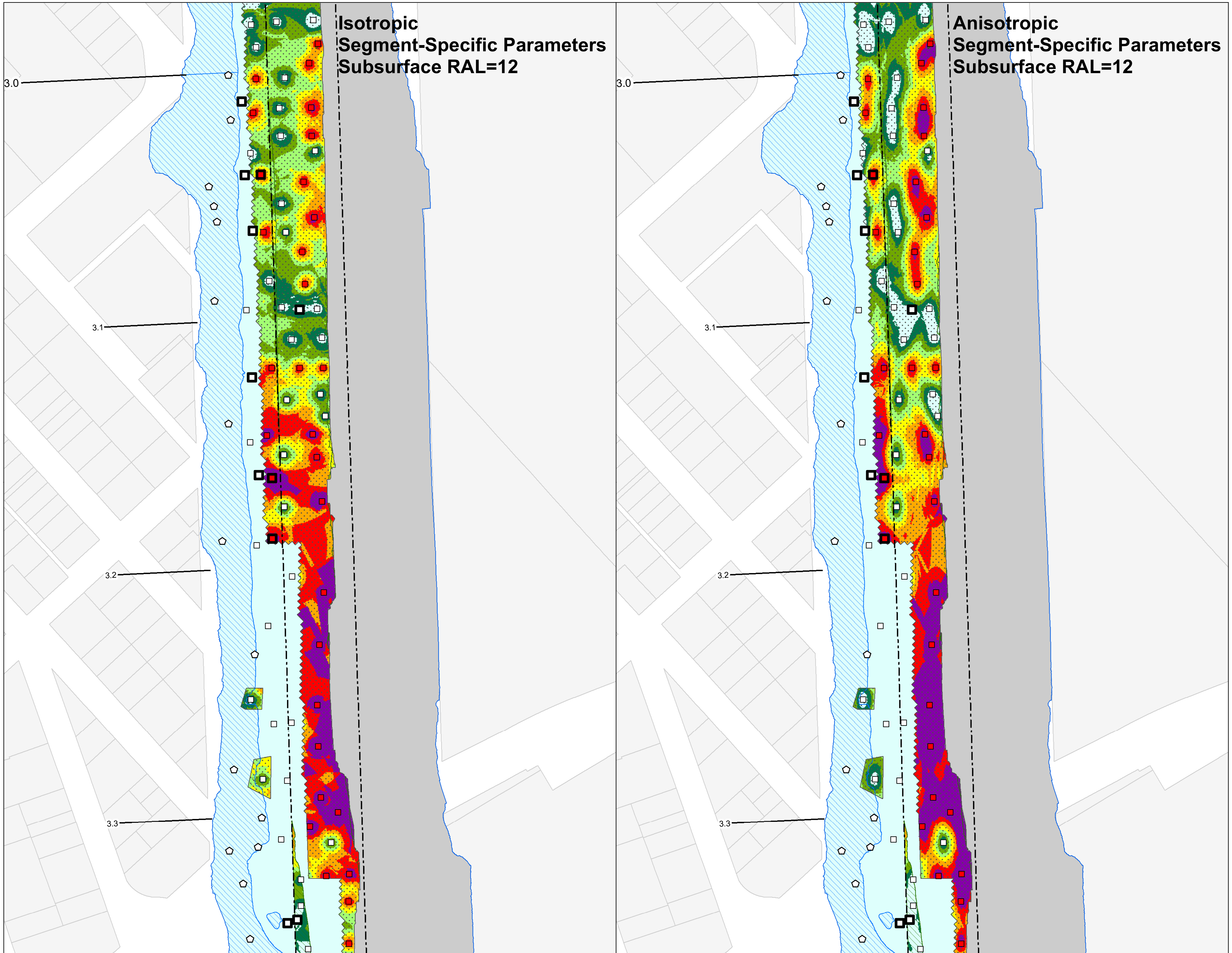

Map A.4-3a. Isotropic versus anisotropic indicator kriging case studies, RM 3.0 to RM 3.3

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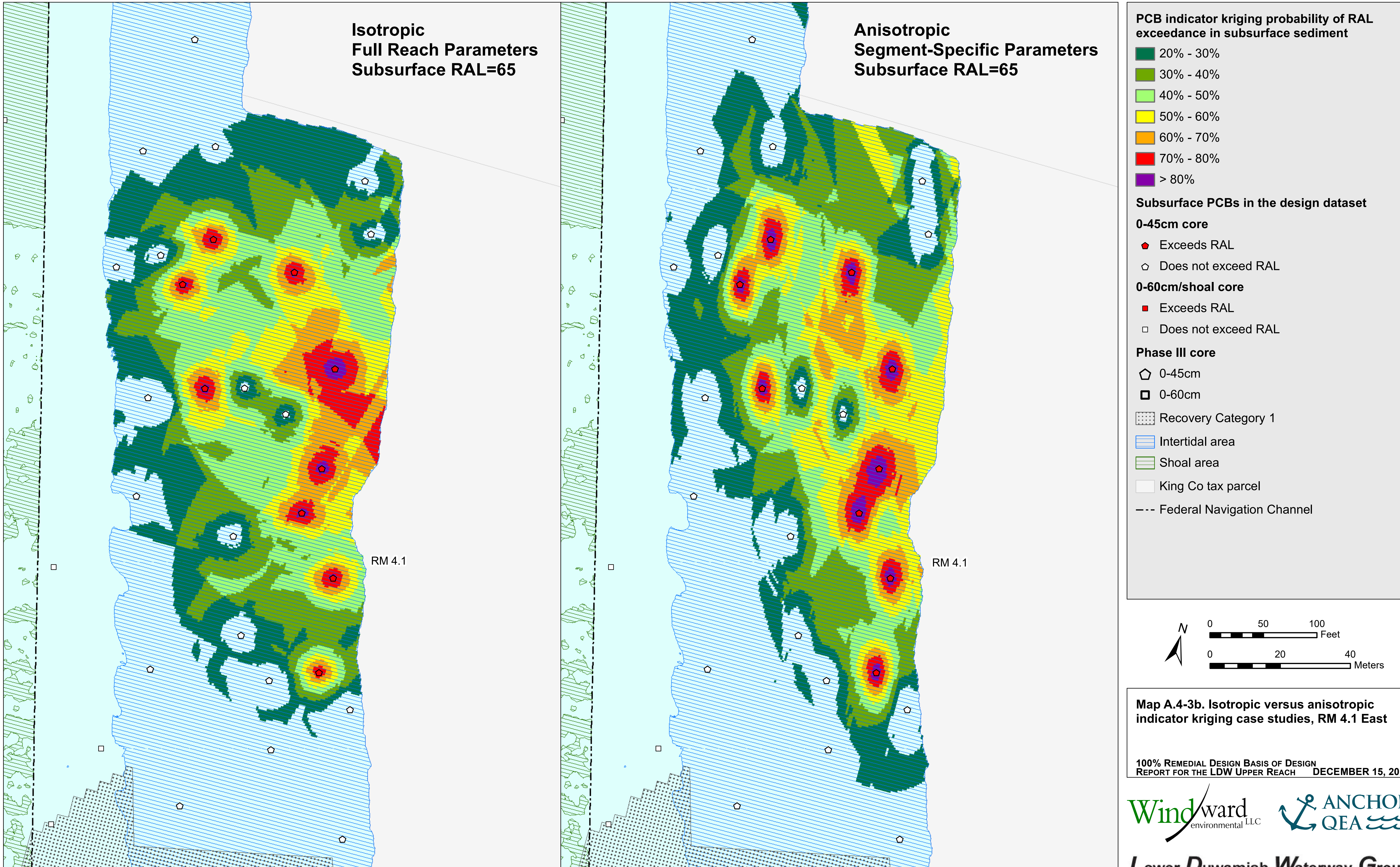
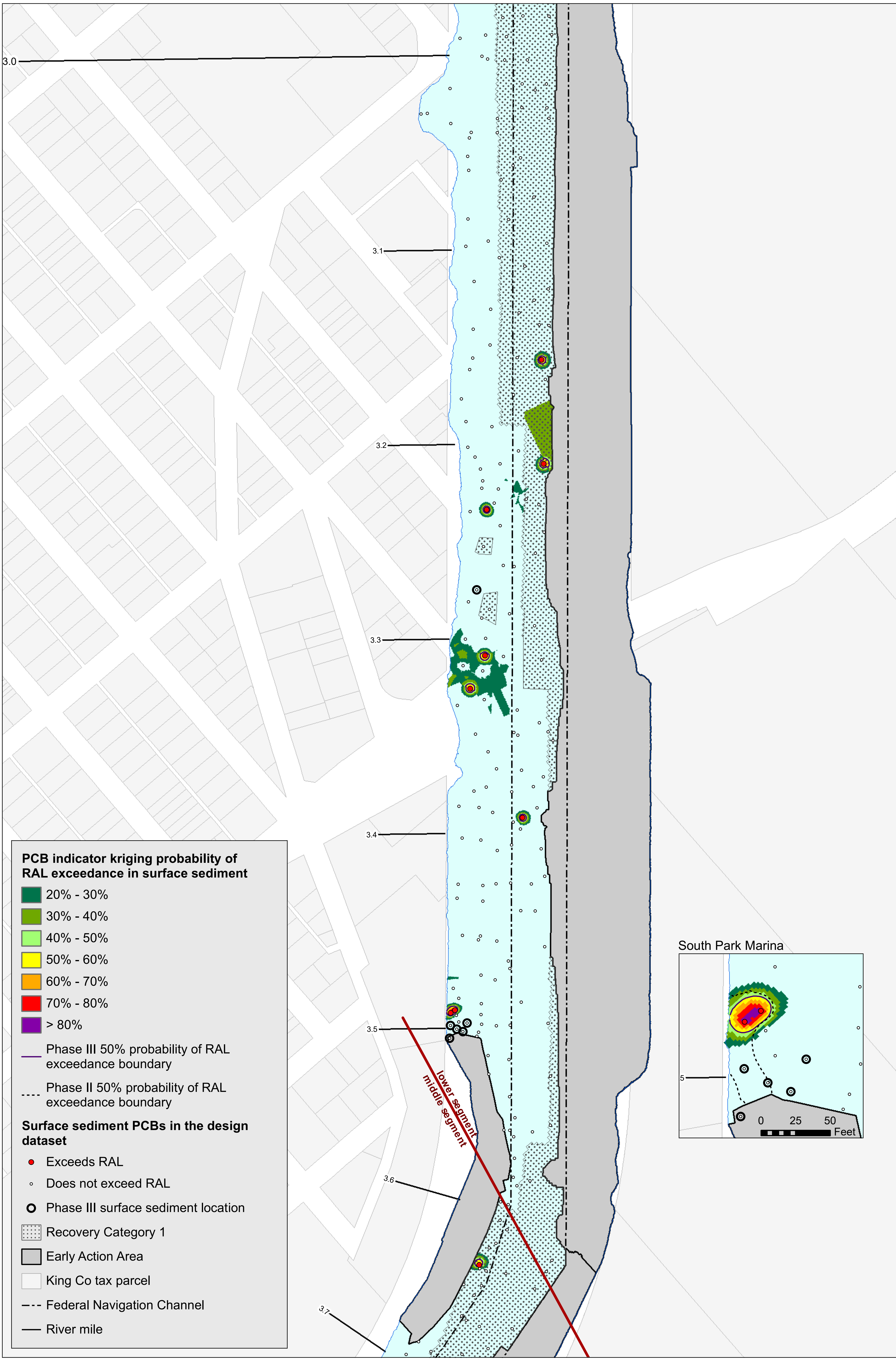


Map A.4-3b. Isotropic versus anisotropic indicator kriging case studies, RM 4.1 East



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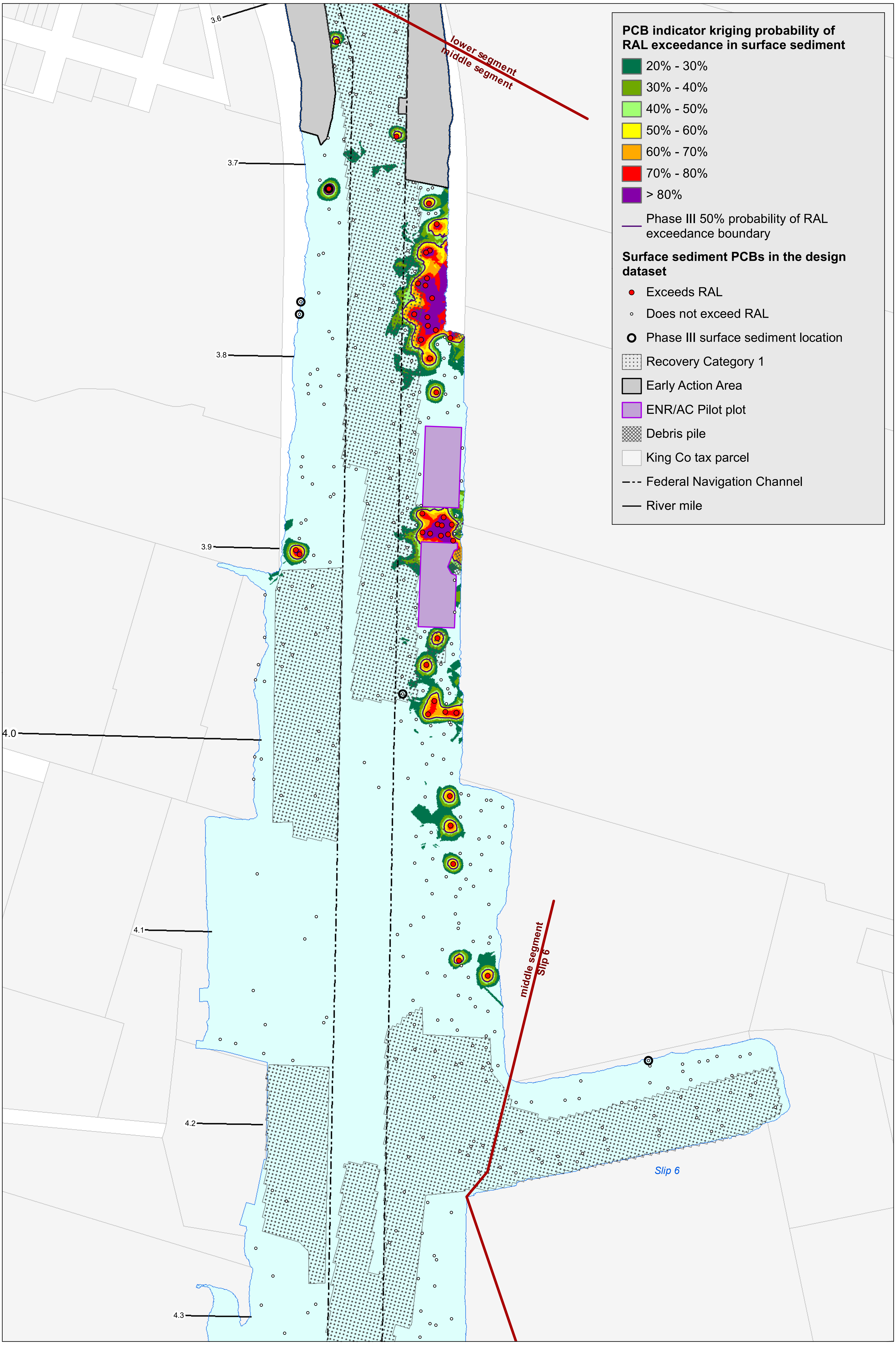
N

0 200 400 Feet

0 50 100 Meters

Map A.4-4a. Updated indicator kriging for surface sediment, RM 3.0 to RM 3.7



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Map A.4-4b. Updated indicator kriging for surface sediment, RM 3.7 to RM 4.3

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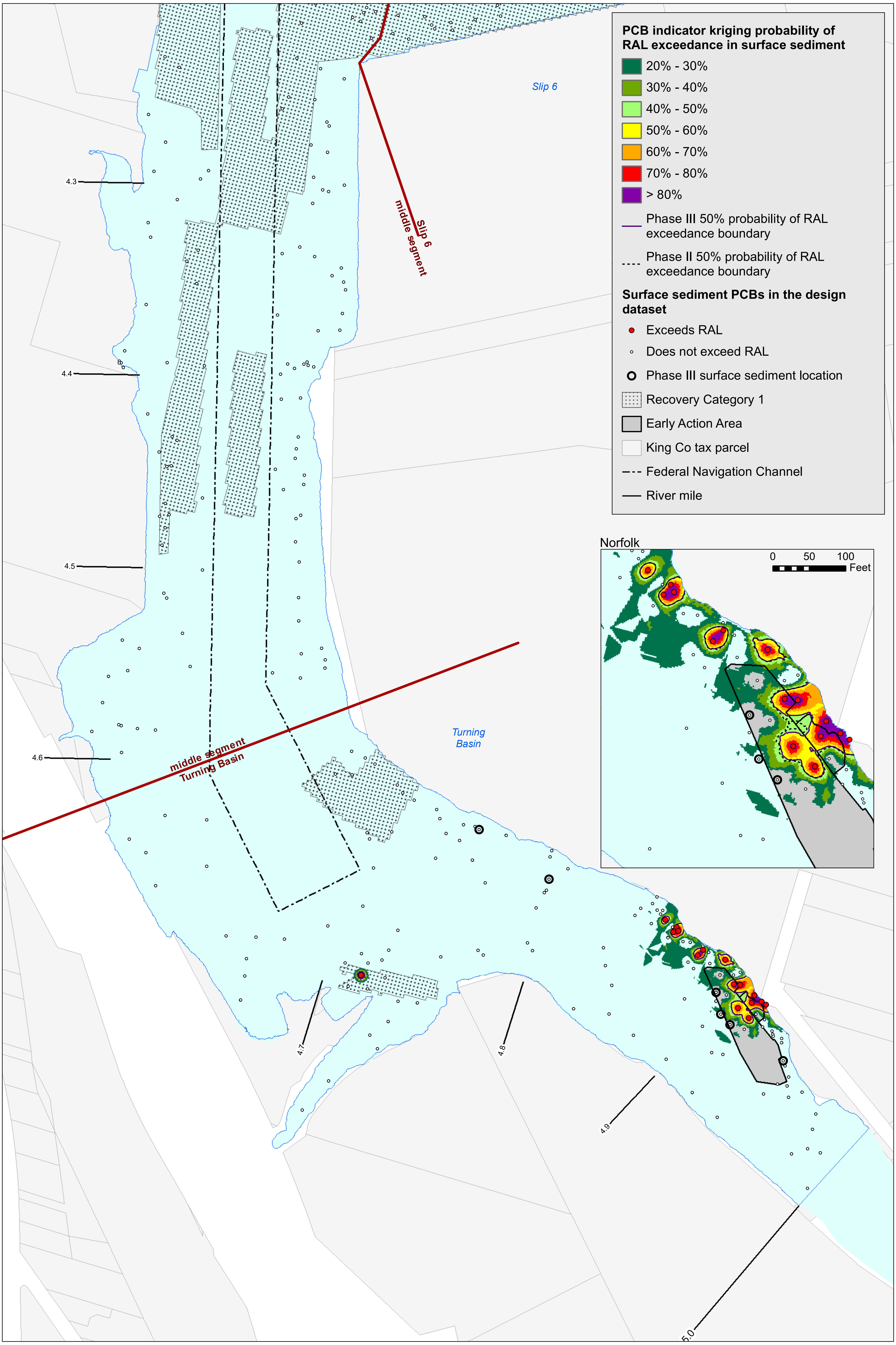

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N

0 200 400 Feet

0 50 100 Meters

Map A.4-4c. Updated indicator kriging for surface sediment, RM 4.3 to RM 5.0

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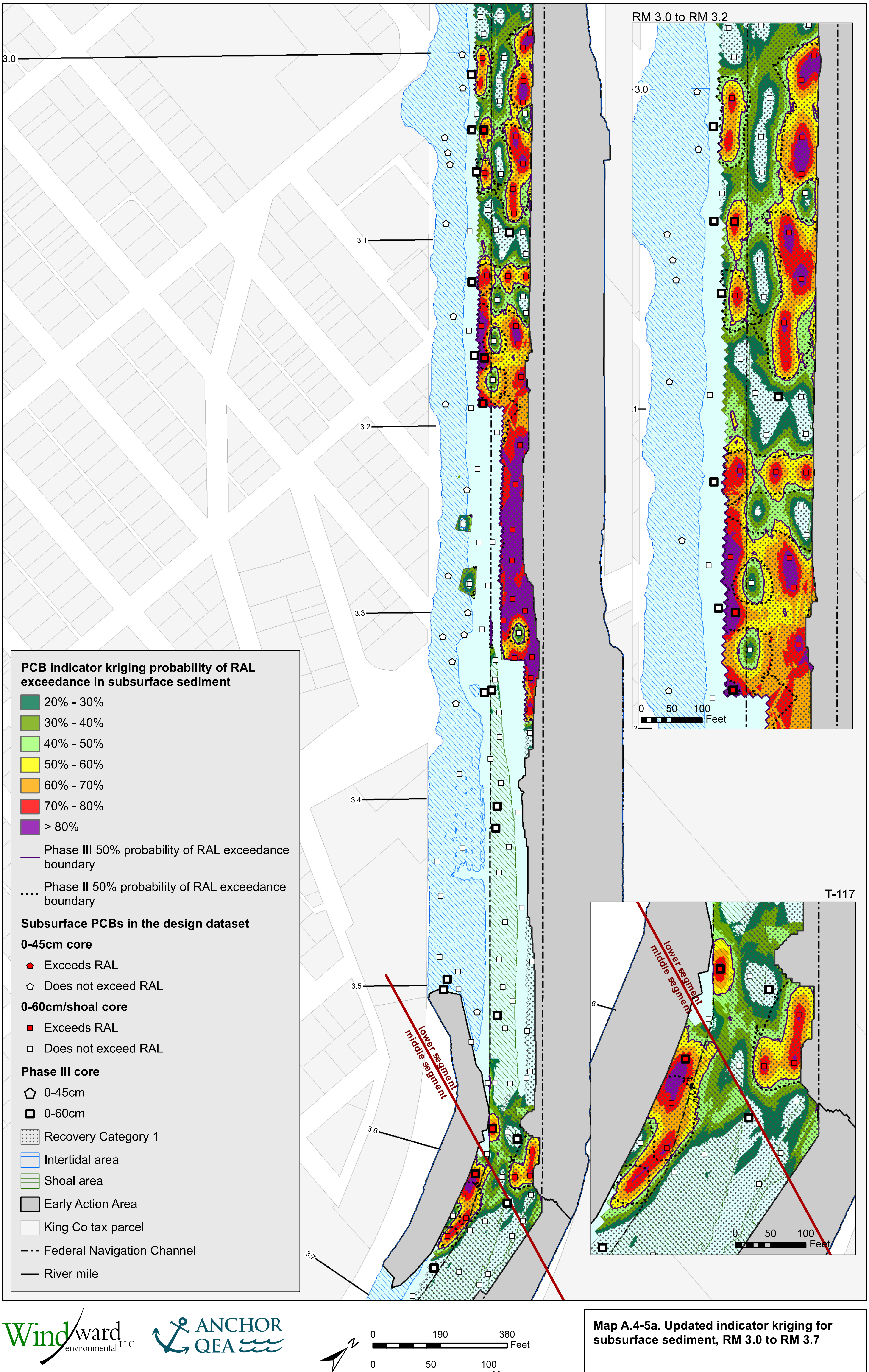

Map A.4-5a. Updated indicator kriging for subsurface sediment, RM 3.0 to RM 3.7

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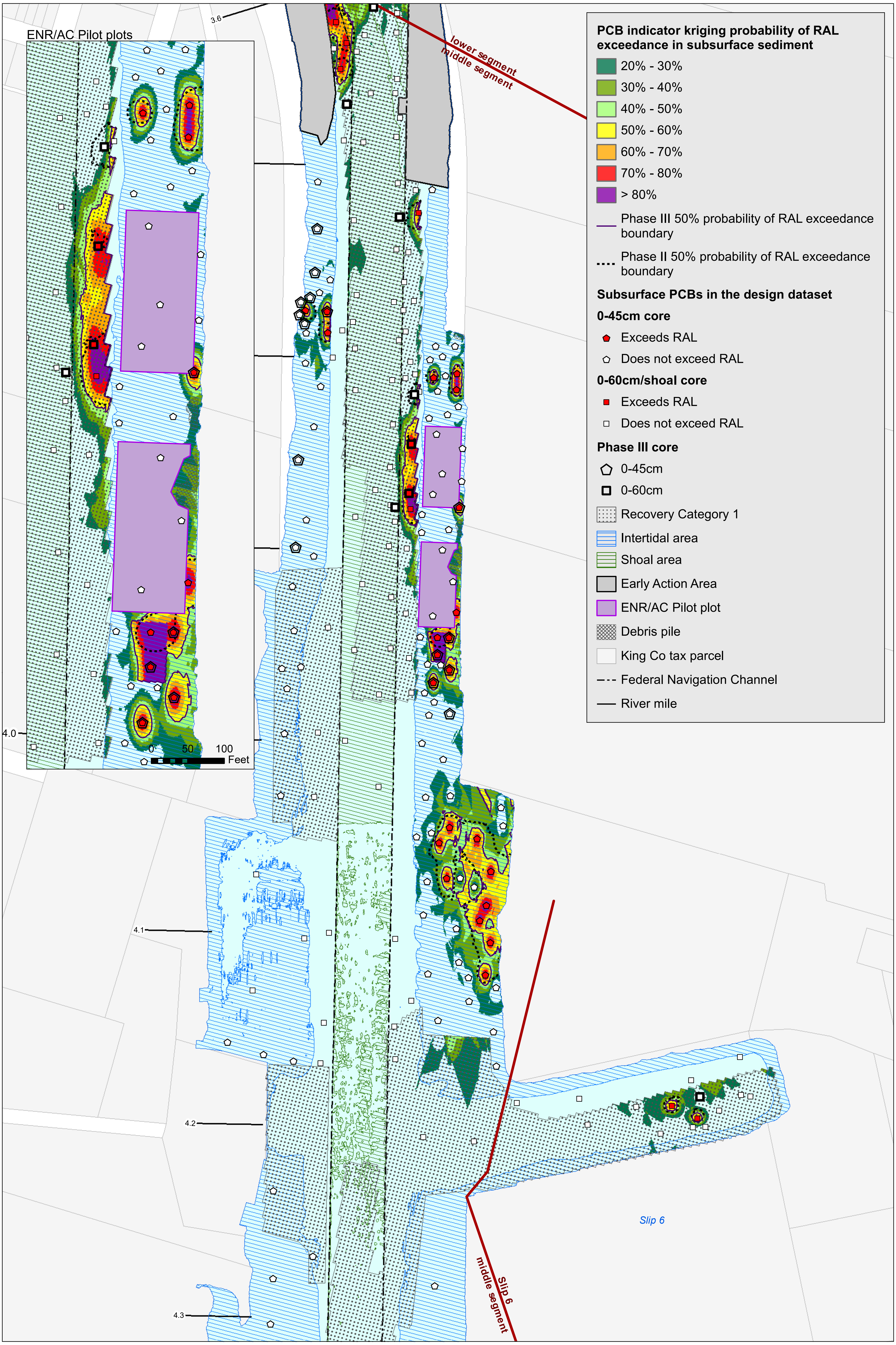

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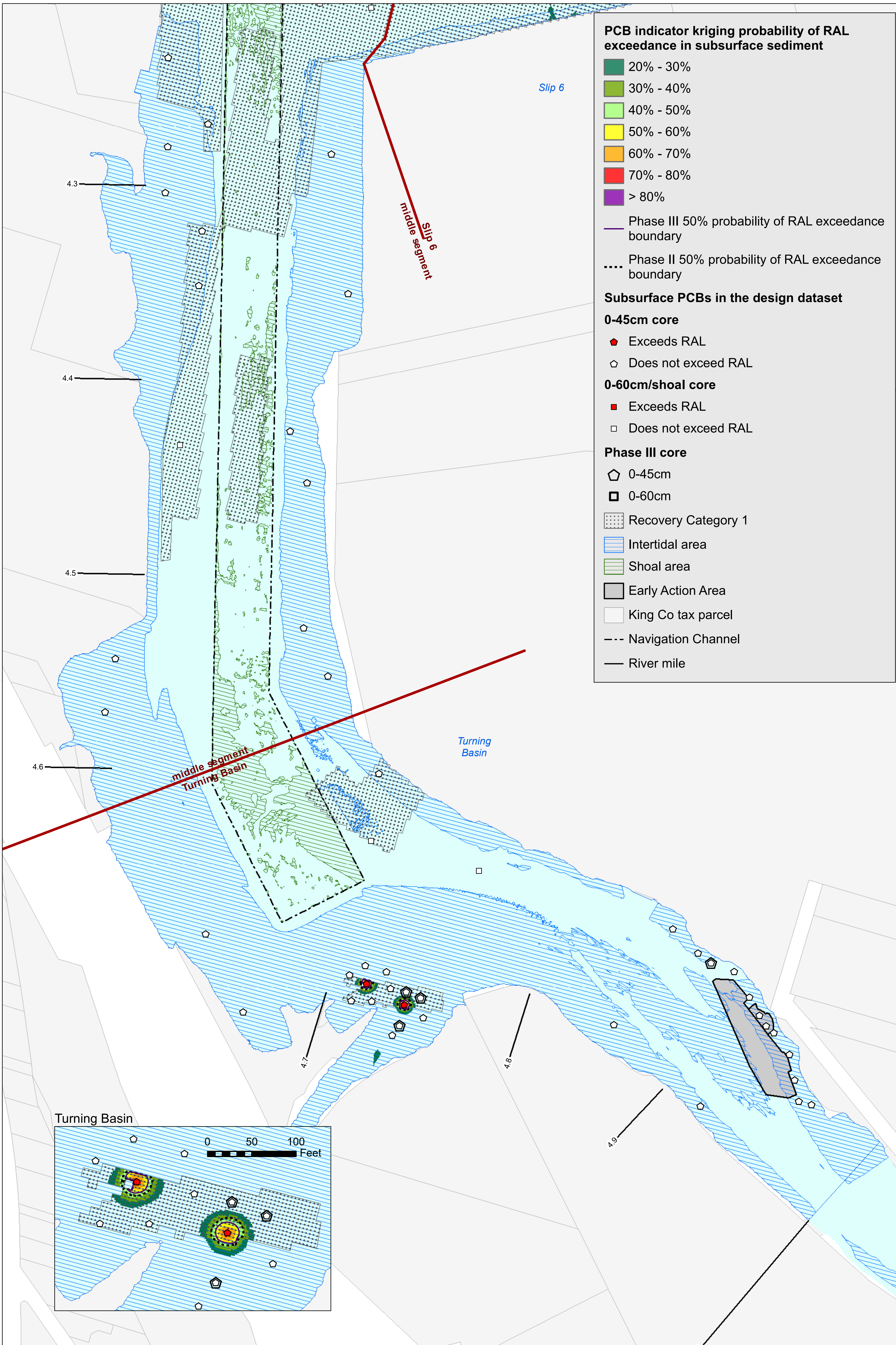
Map A.4-5b. Updated indicator kriging for subsurface sediment, RM 3.7 to RM 4.3



N

0 200 400 Feet

0 50 100 Meters

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Map A.4-5c. Updated indicator kriging for subsurface sediment, RM 4.3 to RM 5.0

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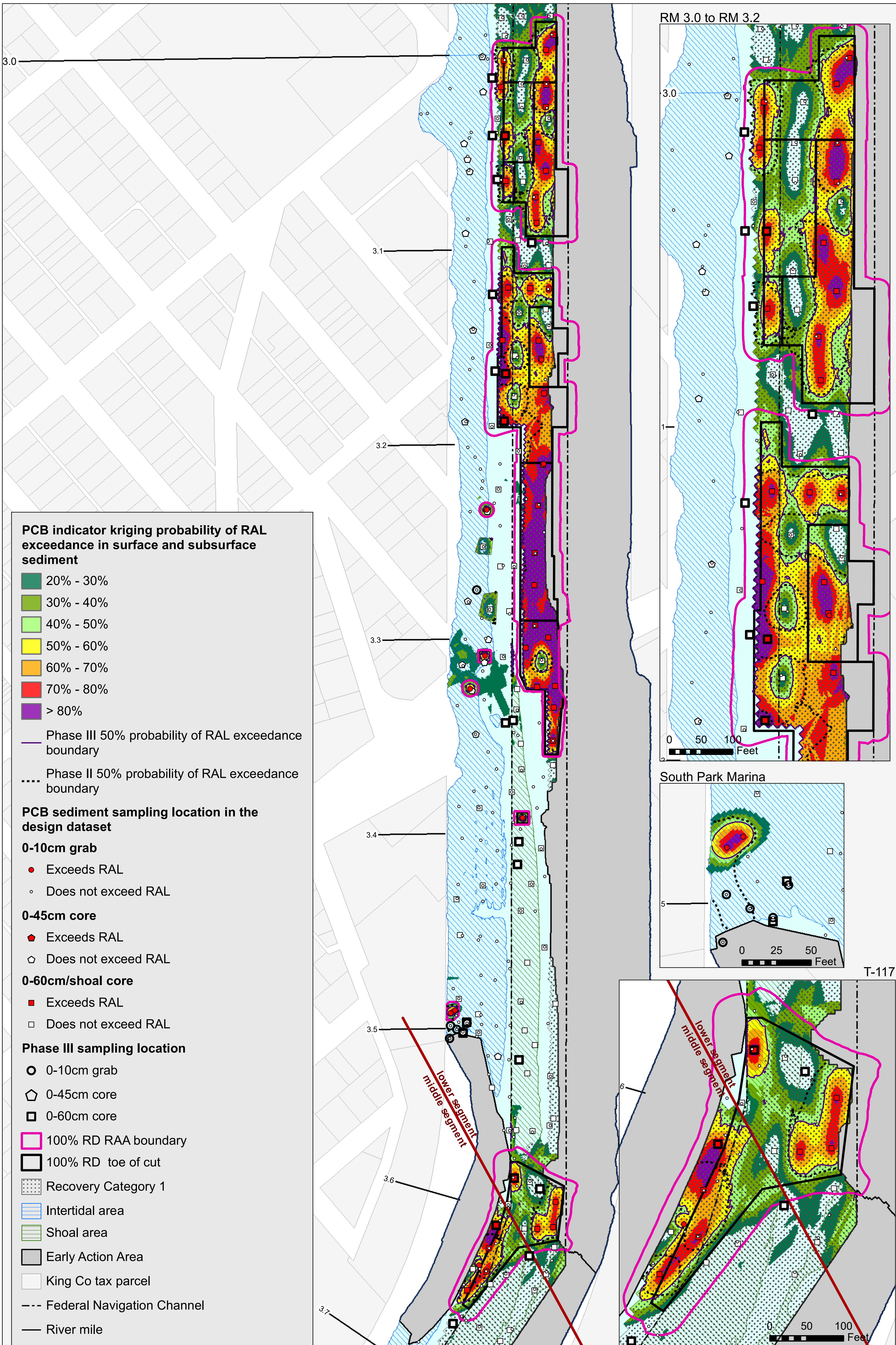

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N

0 200 400 Feet

0 50 100 Meters

Map A.4-6a. Updated indicator kriging for combined surface and subsurface sediment, RM 3.0 to RM 3.7

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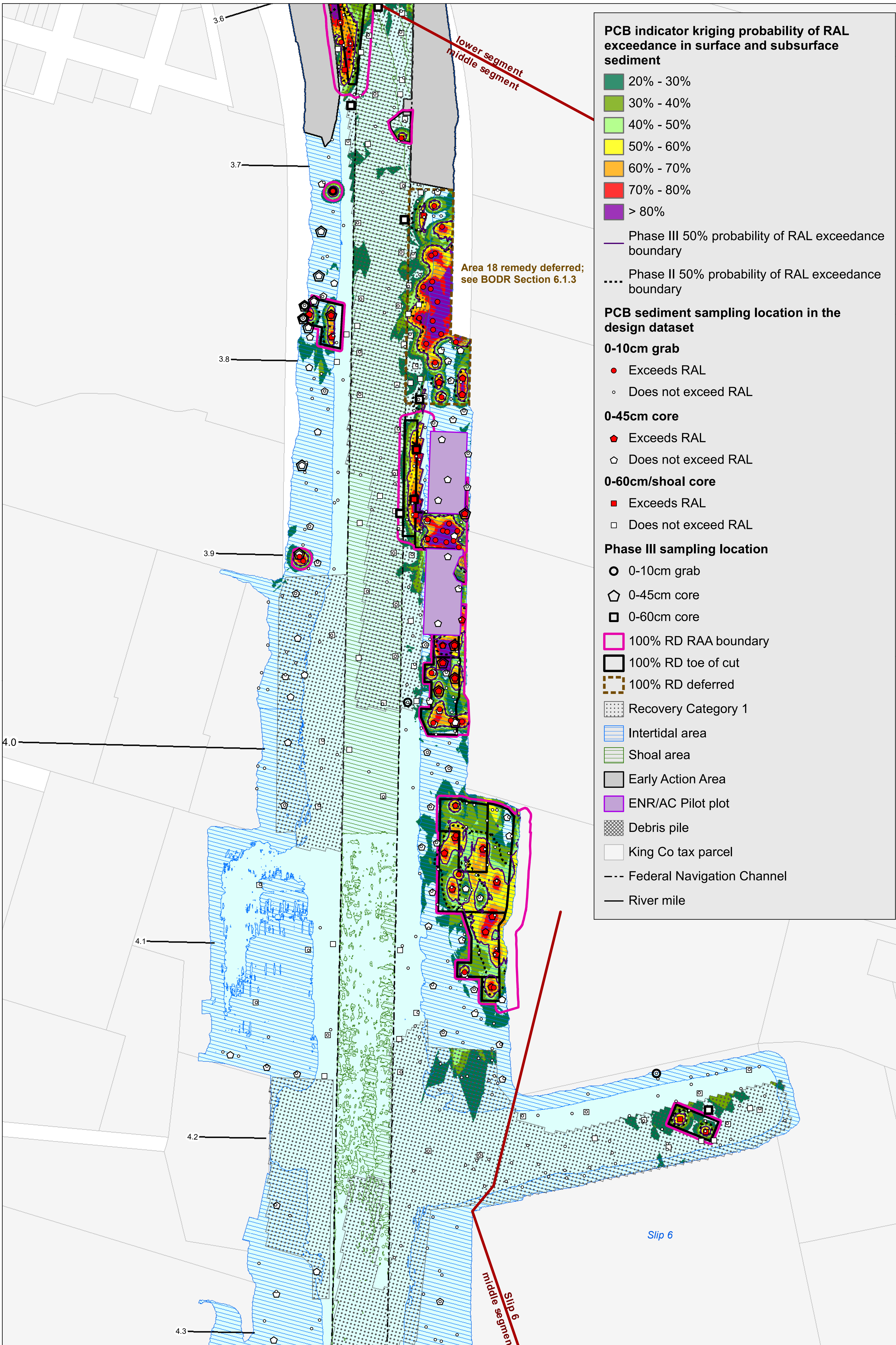

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N

0 200 400 Feet

0 50 100 Meters

Map A.4-6b. Updated indicator kriging for combined surface and subsurface sediment, RM 3.7 to RM 4.3

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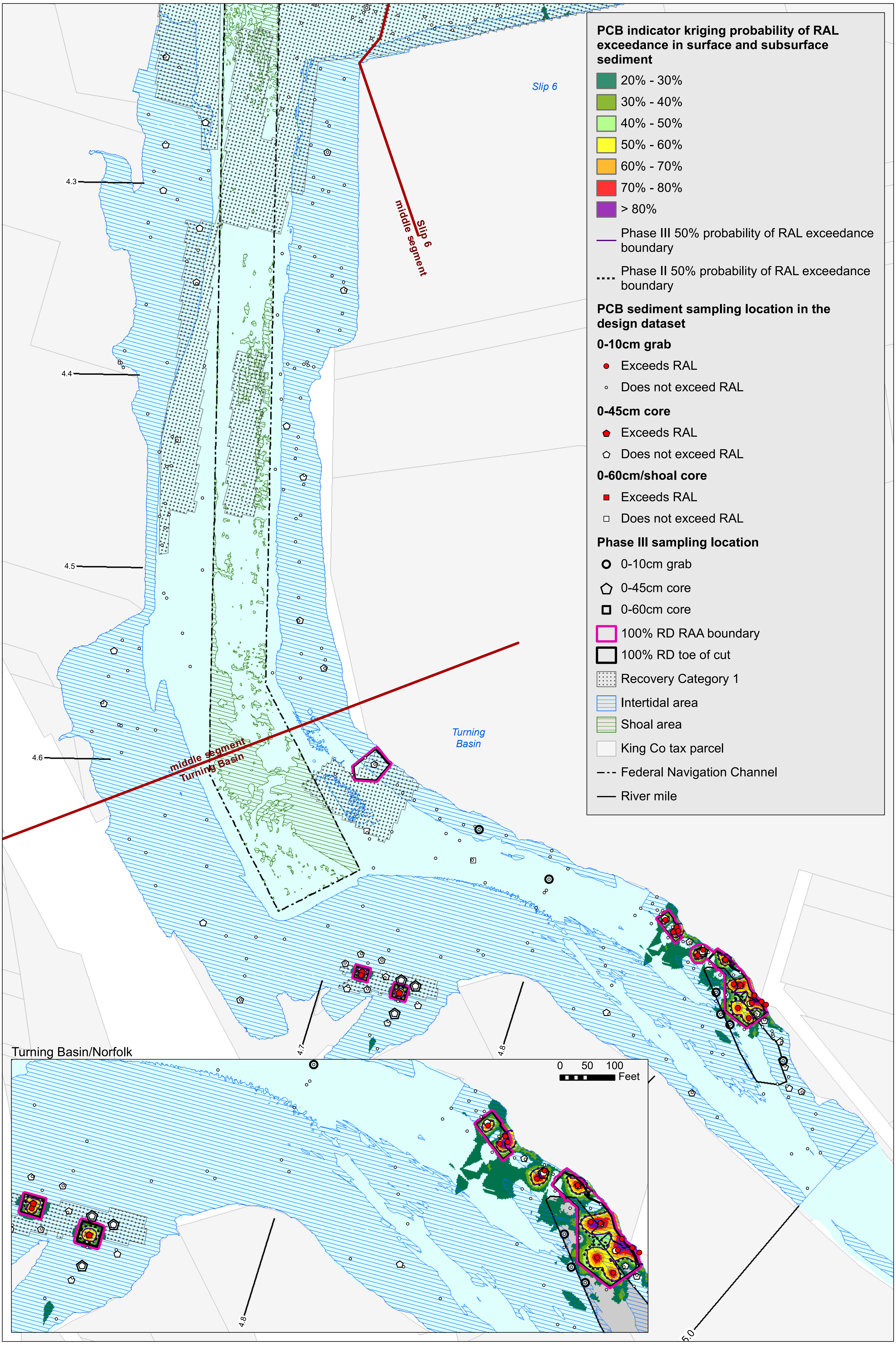

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Map A.4-6c. Updated indicator kriging for combined surface and subsurface sediment, RM 4.3 to RM 5.0

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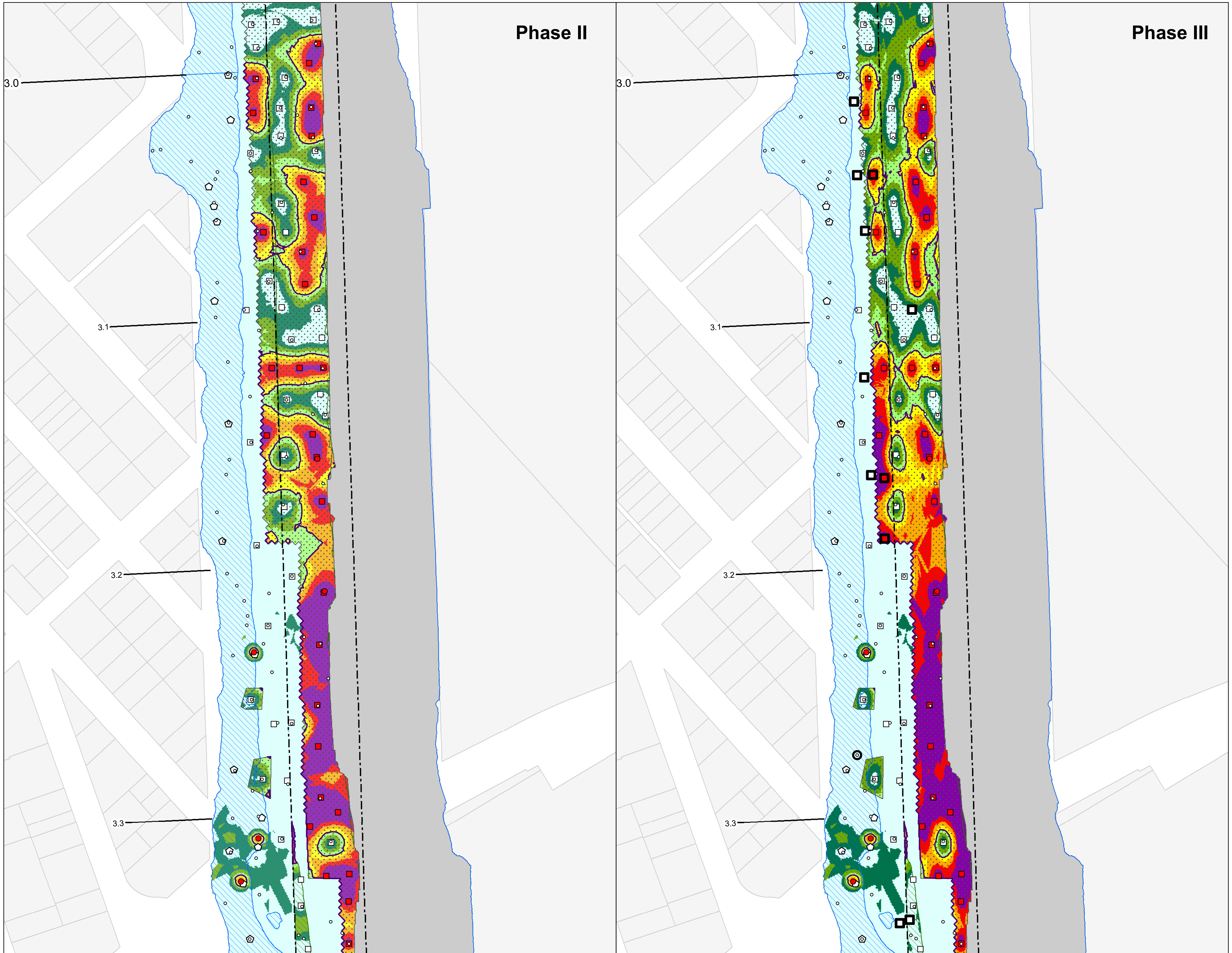

PCB indicator kriging probability of RAL exceedance in surface and subsurface sediment

- 20% - 30%
- 30% - 40%
- 40% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- > 80%
- 50% probability of RAL exceedance boundary

PCB sediment sampling location in the design dataset

0-10cm grab
- Exceeds RAL
- Does not exceed RAL

0-45cm core
- Exceeds RAL
- Does not exceed RAL

0-60cm/shoal core
- Exceeds RAL
- Does not exceed RAL

Phase III sampling location
- 0-10cm grab
- 0-60cm core
- Recovery Category 1
- Intertidal area
- Shoal area
- EAA
- King Co tax parcel
- Federal Navigation Channel
- River mile

N

0 150 300 Feet

0 50 100 Meters

Map A.4-7a. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment, RM 3.0 toRM 3.3

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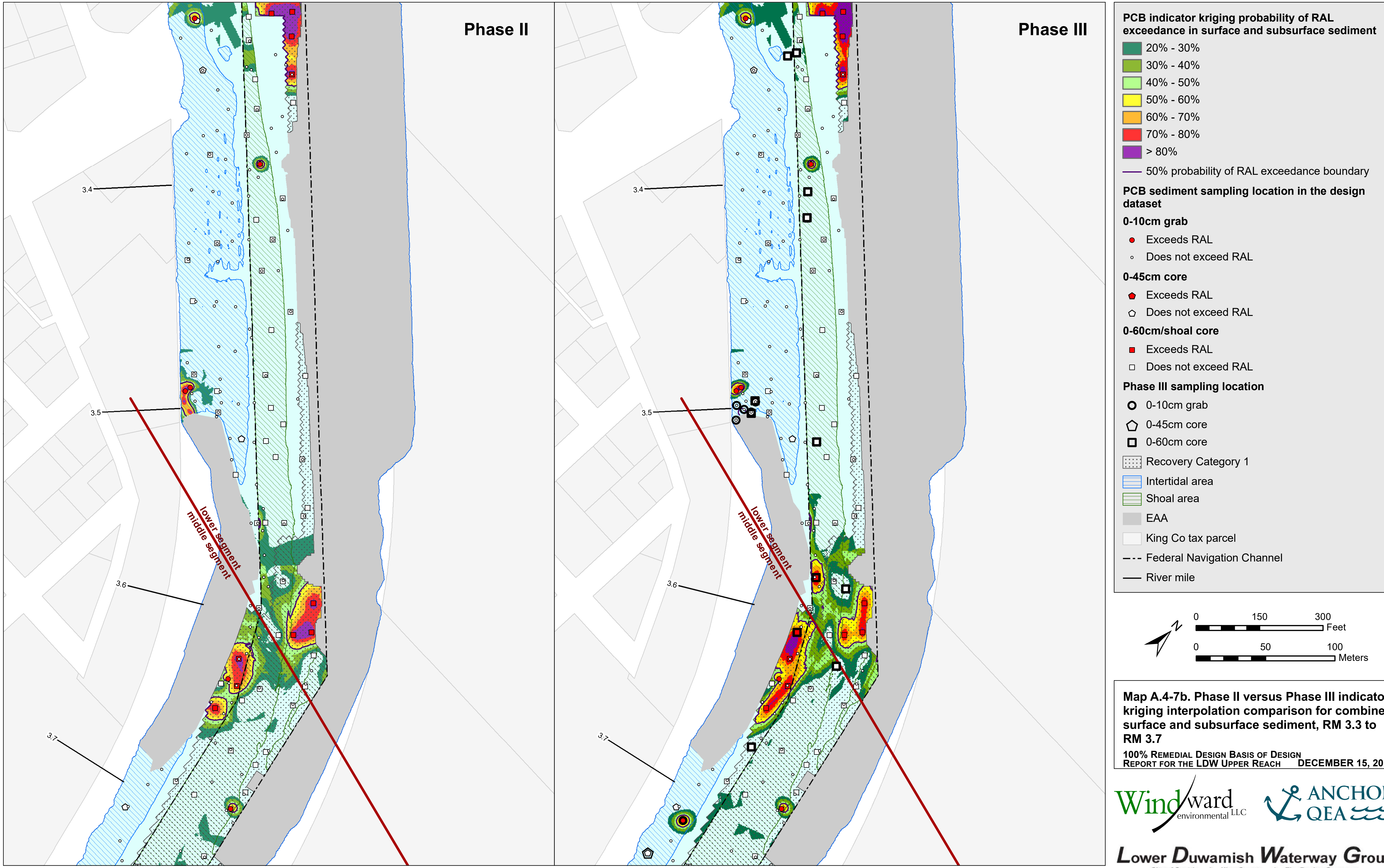

Map A.4-7b. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment, RM 3.3 to RM 3.7

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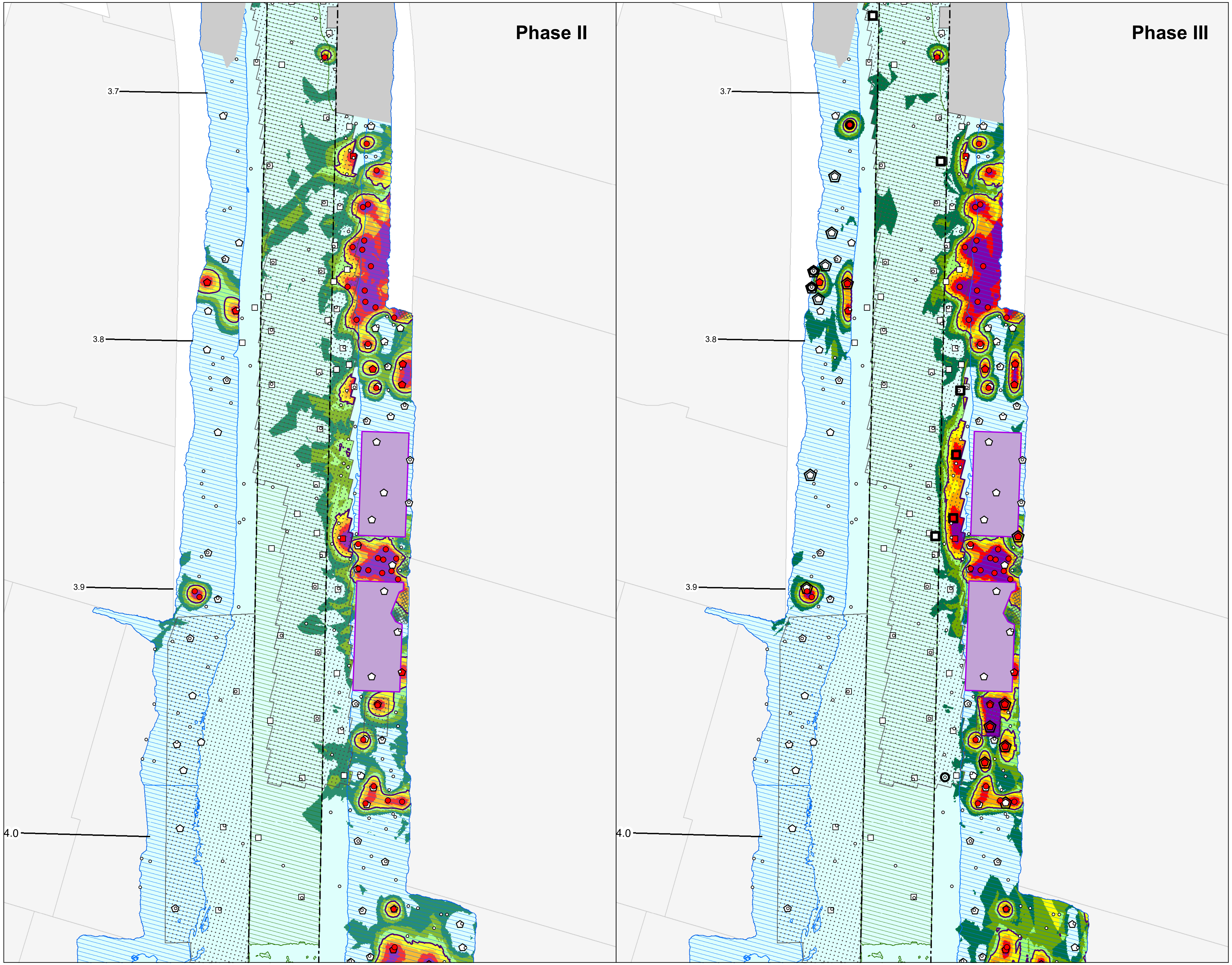

PCB indicator kriging probability of RAL exceedance in surface and subsurface sediment

- 20% - 30%
- 30% - 40%
- 40% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- > 80%
- 50% probability of RAL exceedance boundary

PCB sediment sampling location in the design dataset

0-10cm grab

- Exceeds RAL
- Does not exceed RAL

0-45cm core

- Exceeds RAL
- Does not exceed RAL

0-60cm/shoal core

- Exceeds RAL
- Does not exceed RAL

Phase III sampling location

- 0-10cm grab
- 0-45cm core
- 0-60cm core
- Recovery Category 1
- Intertidal area
- Shoal area
- EAA
- ENR/AC Pilot plot
- Debris pile
- King Co tax parcel
- Federal Navigation Channel
- River mile

N

0 150 300 Feet

0 50 100 Meters

Map A.4-7c. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment, RM 3.7 to RM 4.0

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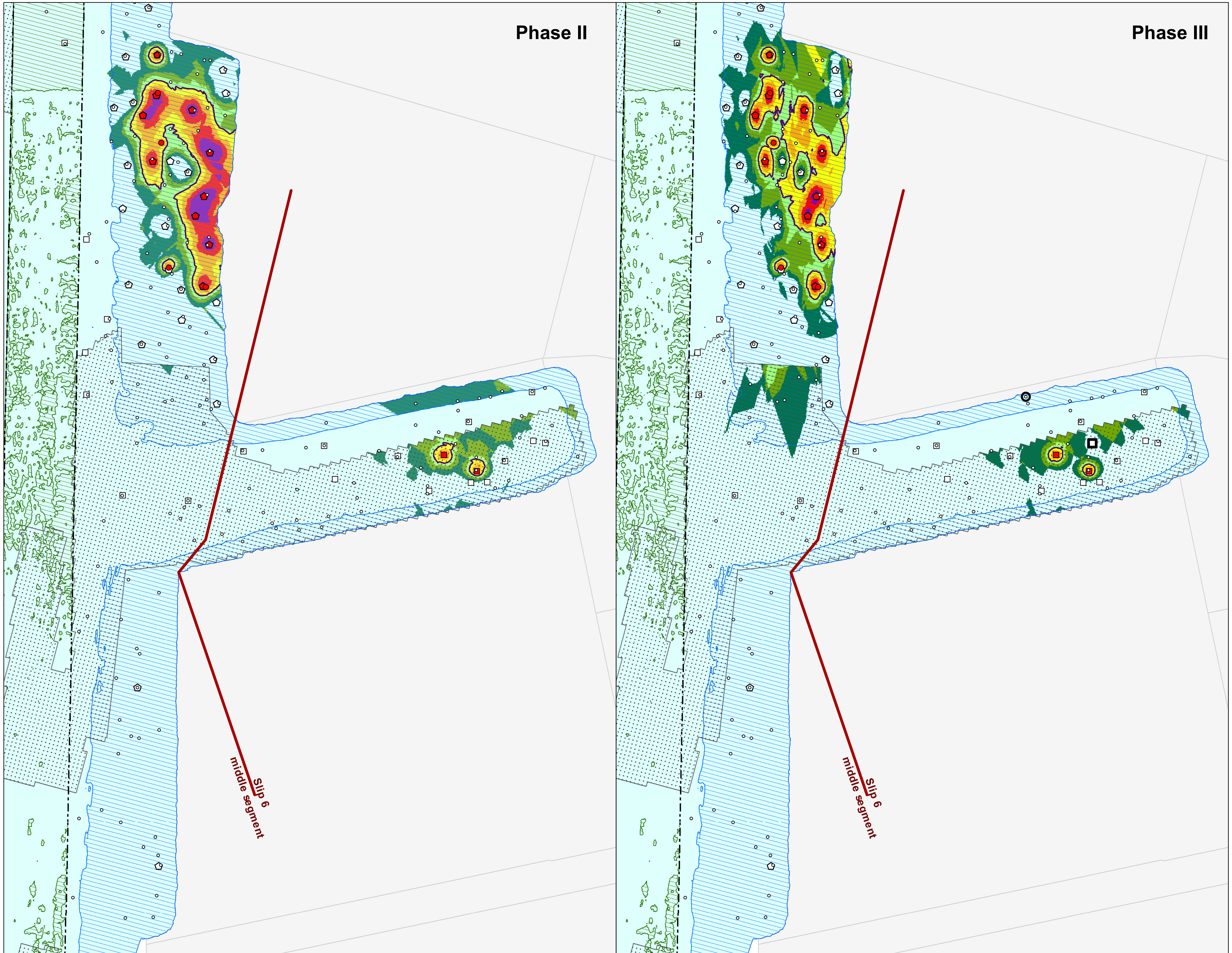

PCB indicator kriging probability of RAL exceedance in surface and subsurface sediment

- 20% - 30%
- 30% - 40%
- 40% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- > 80%
- 50% probability of RAL exceedance boundary

PCB sediment sampling location in the design dataset

0-10cm grab

- Exceeds RAL
- Does not exceed RAL

0-45cm core

- Exceeds RAL
- Does not exceed RAL

0-60cm/shoal core

- Exceeds RAL
- Does not exceed RAL

Phase III sampling location

- 0-10cm grab
- 0-45cm core
- 0-60cm core
- Recovery Category 1
- Intertidal area
- Shoal area
- King Co tax parcel
- Federal Navigation Channel

N

0 150 300 Feet

0 50 100 Meters

Map A.4-7d. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment, RM 4.0 to RM 4.4

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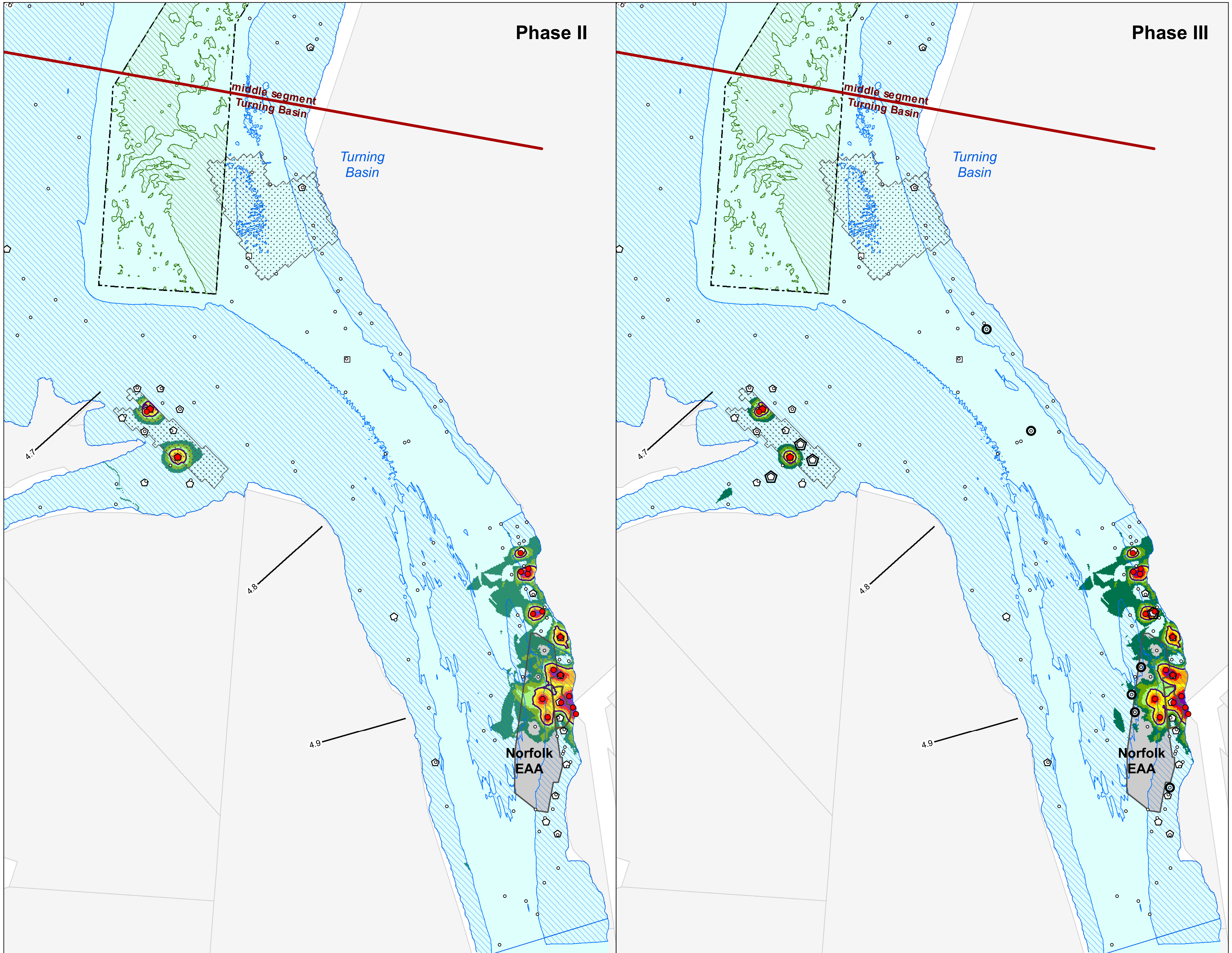

PCB indicator kriging probability of RAL exceedance in surface and subsurface sediment

- 20% - 30%
- 30% - 40%
- 40% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- > 80%
- 50% probability of RAL exceedance boundary

PCB sediment sampling location in the design dataset

0-10cm grab

- Exceeds RAL
- Does not exceed RAL

0-45cm core

- Exceeds RAL (2)
- Does not exceed RAL (28)

0-60cm/shoal core

- Does not exceed RAL (2)

Phase III sampling location

- 0-10cm grab (6)
- 0-45cm core (4)
- Recovery Category 1
- Intertidal area
- Shoal area
- Boeing South Storm Drain removal area
- EAA
- King Co tax parcel
- Federal Navigation Channel
- River mile

0 150 300 Feet

0 50 100 Meters

Map A.4-7e. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment, RM 4.7 to RM 5.0

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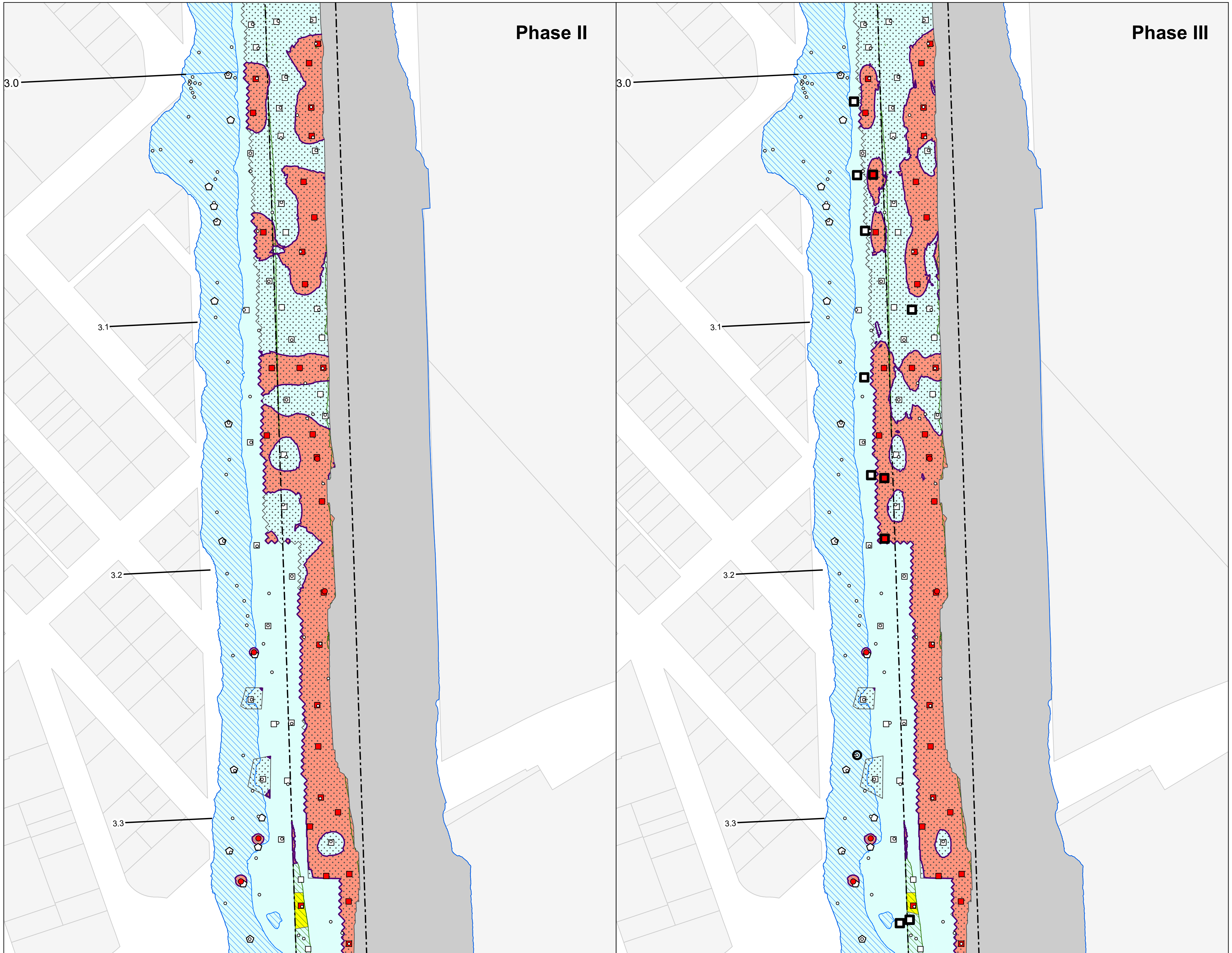

Combined sediment PCB indicator kriging RAL exceedance area

Additional Thiessen polygon RAL exceedance area for other COCs

50% probability of PCB RAL exceedance boundary

Exceedance status in surface and subsurface sediment in the design dataset

0-10cm sample

- Exceeds RAL
- Does not exceed RAL

0-45cm core

- Exceeds RAL
- Does not exceed RAL

0-60cm/shoal core

- Exceeds RAL
- Does not exceed RAL

Phase III sample

- 0-10cm
- 0-60cm

Recovery Category 1

Intertidal area

Shoal area

EAA

King Co tax parcel

Federal Navigation Channel

River mile

0 150 300 Feet

0 50 100 Meters

Map A.4-8a. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment and Thiessen polygons for other COCs, RM 3.0 to RM 3.3

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Map A.4-8b. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment and Thiessen polygons for other COCs, RM 3.3 to RM 3.7

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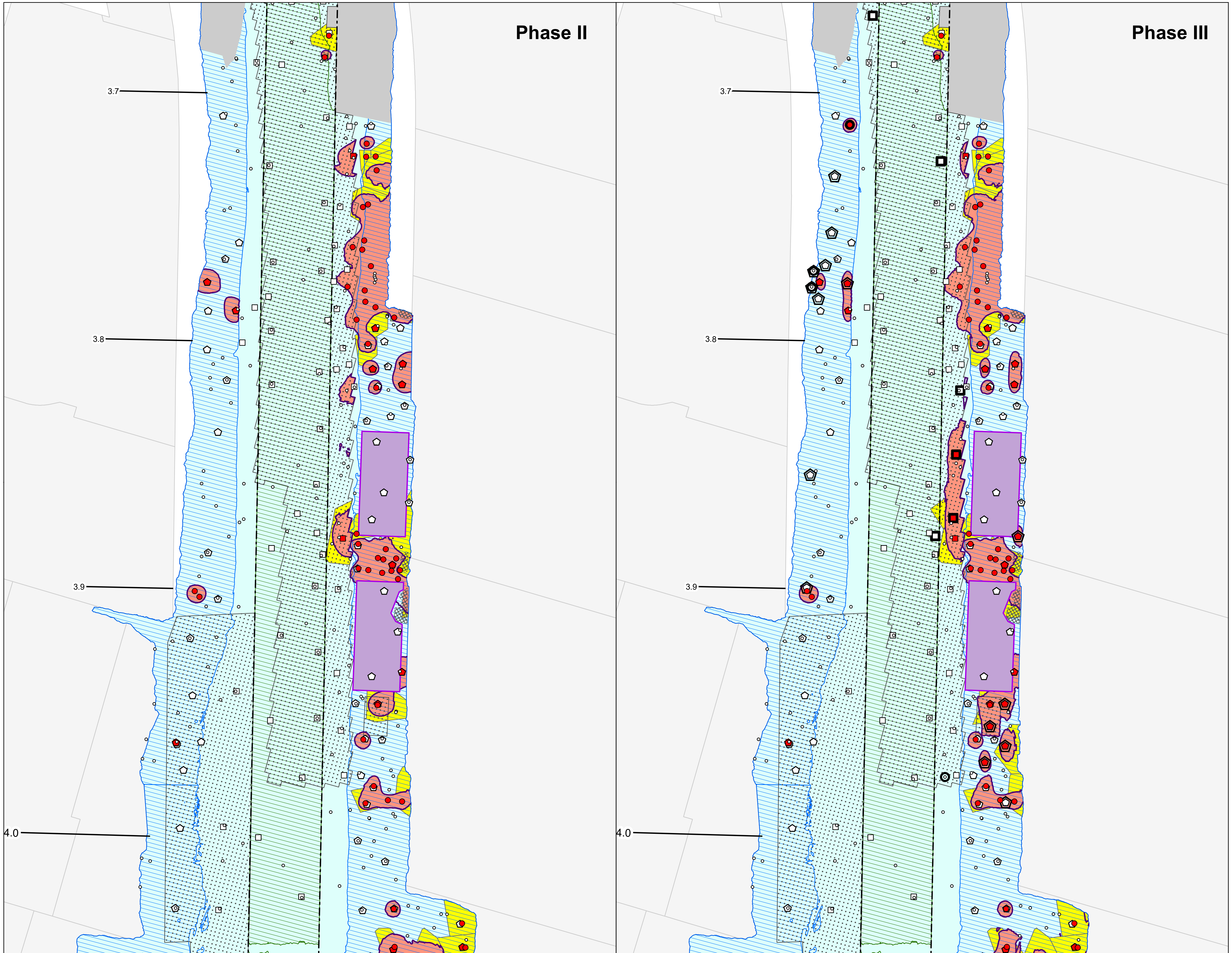

Combined sediment PCB indicator kriging RAL exceedance area
Additional Thiessen polygon RAL exceedance area for other COCs
50% probability of PCB RAL exceedance boundary

Exceedance status in surface and subsurface sediment in the design dataset

0-10cm sample
- Exceeds RAL
- Does not exceed RAL

0-45cm core
- Exceeds RAL
- Does not exceed RAL

0-60cm/shoal core
- Exceeds RAL
- Does not exceed RAL

Phase III sample
- 0-10cm
- 0-45cm
- 0-60cm

Recovery Category 1
Intertidal area
Shoal area
EAA
ENR/AC Pilot plot
Debris pile
King Co tax parcel
Federal Navigation Channel
River mile

N
0 150 300 Feet
0 50 100 Meters

Map A.4-8c. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment and Thiessen polygons for other COCs, RM 3.7 to RM 4.0

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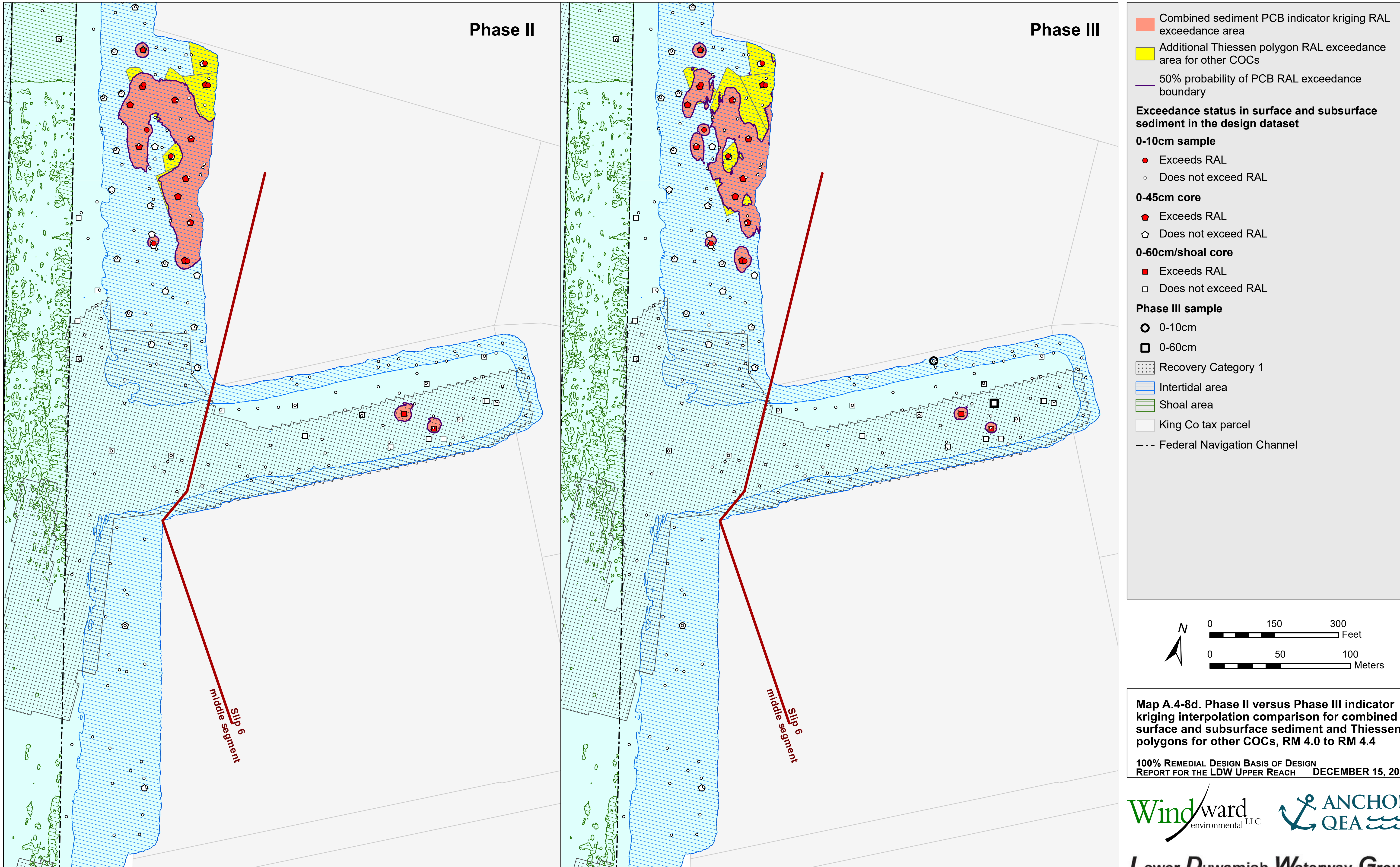

Map A.4-8d. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment and Thiessen polygons for other COCs, RM 4.0 to RM 4.4

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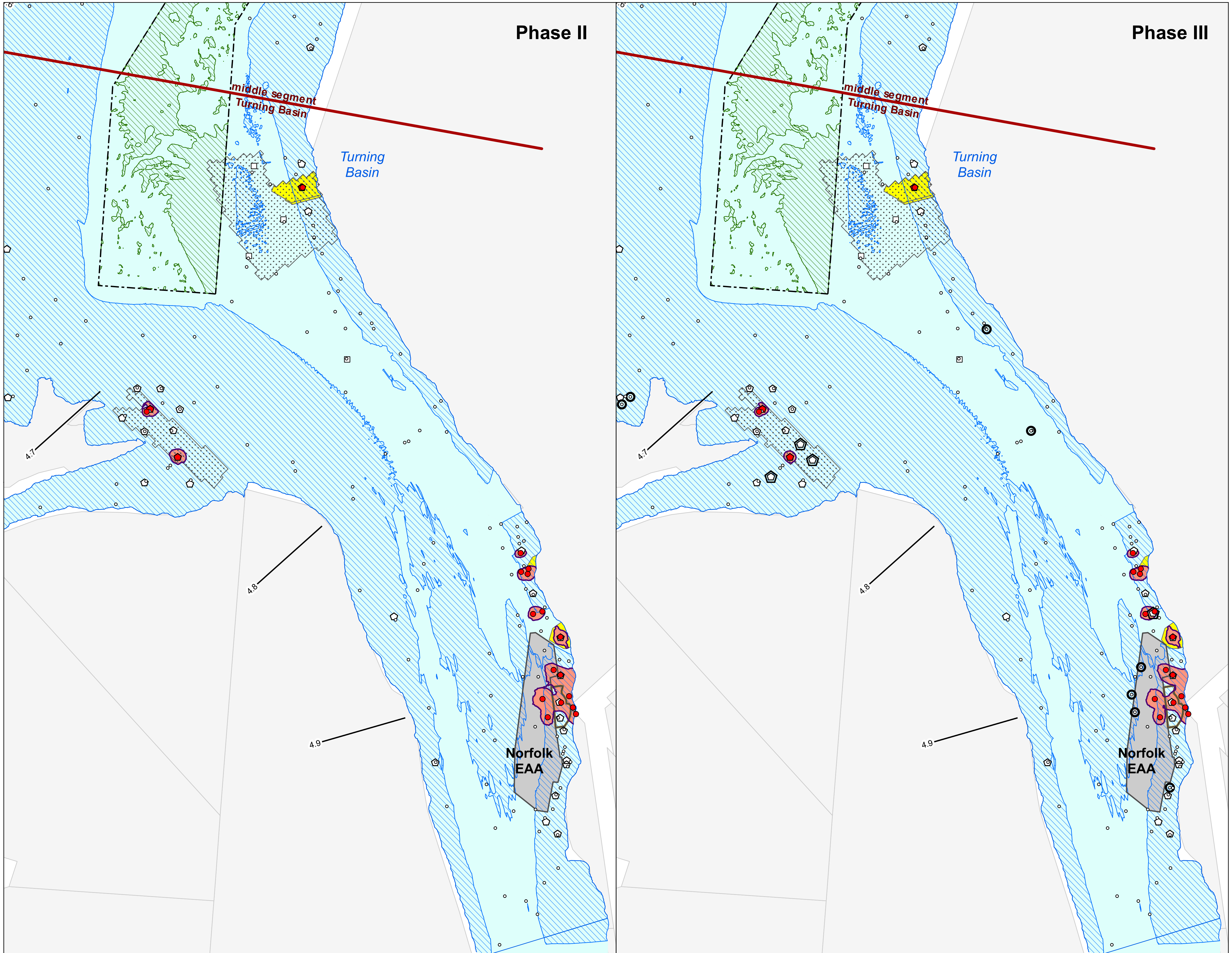

Combined sediment PCB indicator kriging RAL exceedance area
Additional Thiessen polygon RAL exceedance area for other COCs
50% probability of PCB RAL exceedance boundary

Exceedance status in surface and subsurface sediment in the design dataset

0-10cm sample
- Exceeds RAL
- Does not exceed RAL

0-45cm core
- Exceeds RAL
- Does not exceed RAL

0-60cm/shoal core
- Exceeds RAL
- Does not exceed RAL

Phase III sample
- 0-10cm
- 0-45cm

Recovery Category 1
Intertidal area
Shoal area
Boeing South Storm Drain removal area
EAA
King Co tax parcel
Federal Navigation Channel
River mile

Map A.4-8e. Phase II versus Phase III indicator kriging interpolation comparison for combined surface and subsurface sediment and Thiessen polygons for other COCs, RM 4.4 to RM 5.0

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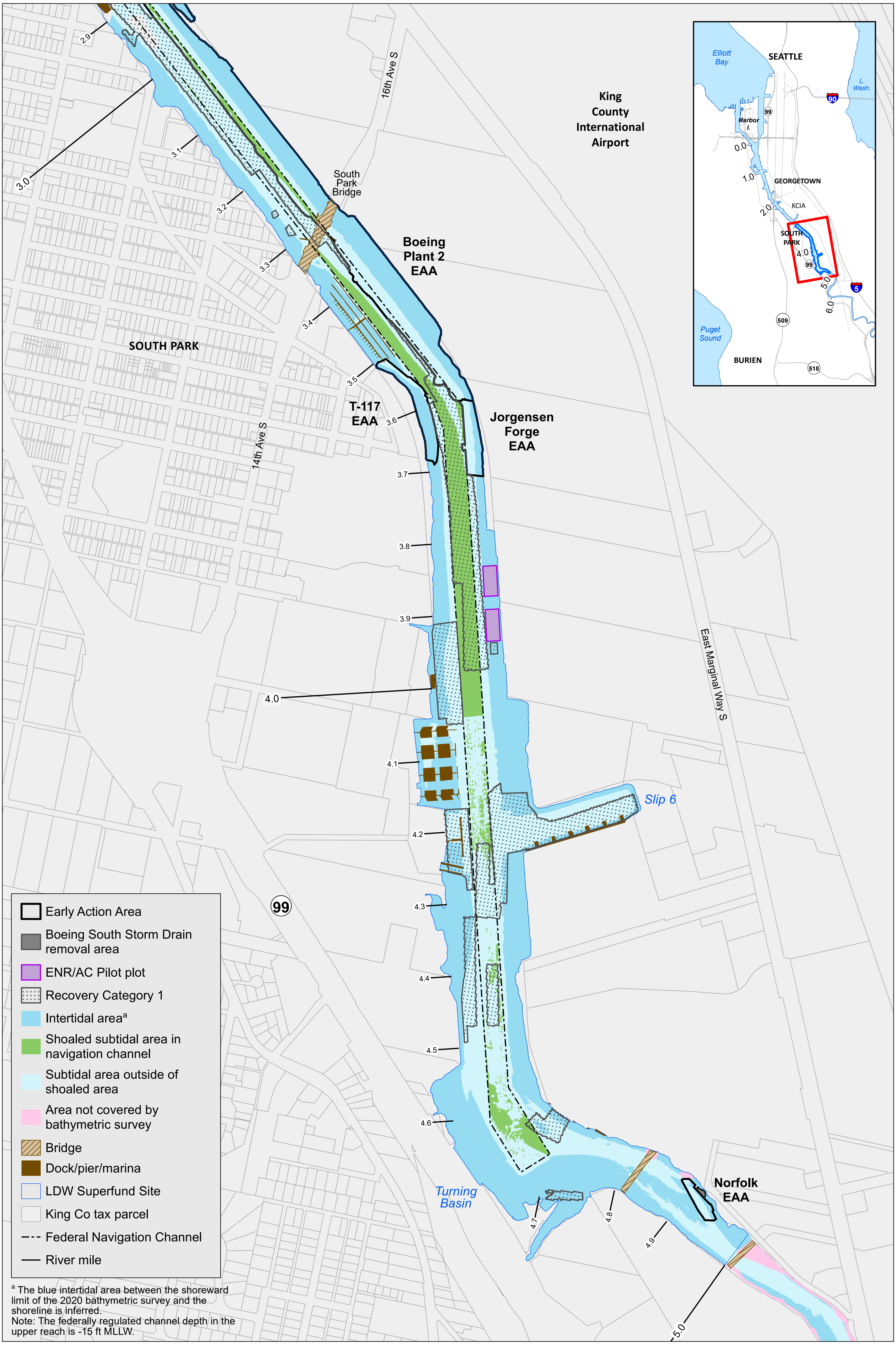
Maps



[a] The blue intertidal area between the shoreward limit of the 2020 bathymetric survey and the shoreline is inferred.
Note: The federally regulated channel depth in the upper reach is -15 ft MLLW.

N
0 500 1,000 Feet
0 200 400 Meters

Map A-1. Upper reach of the LDW

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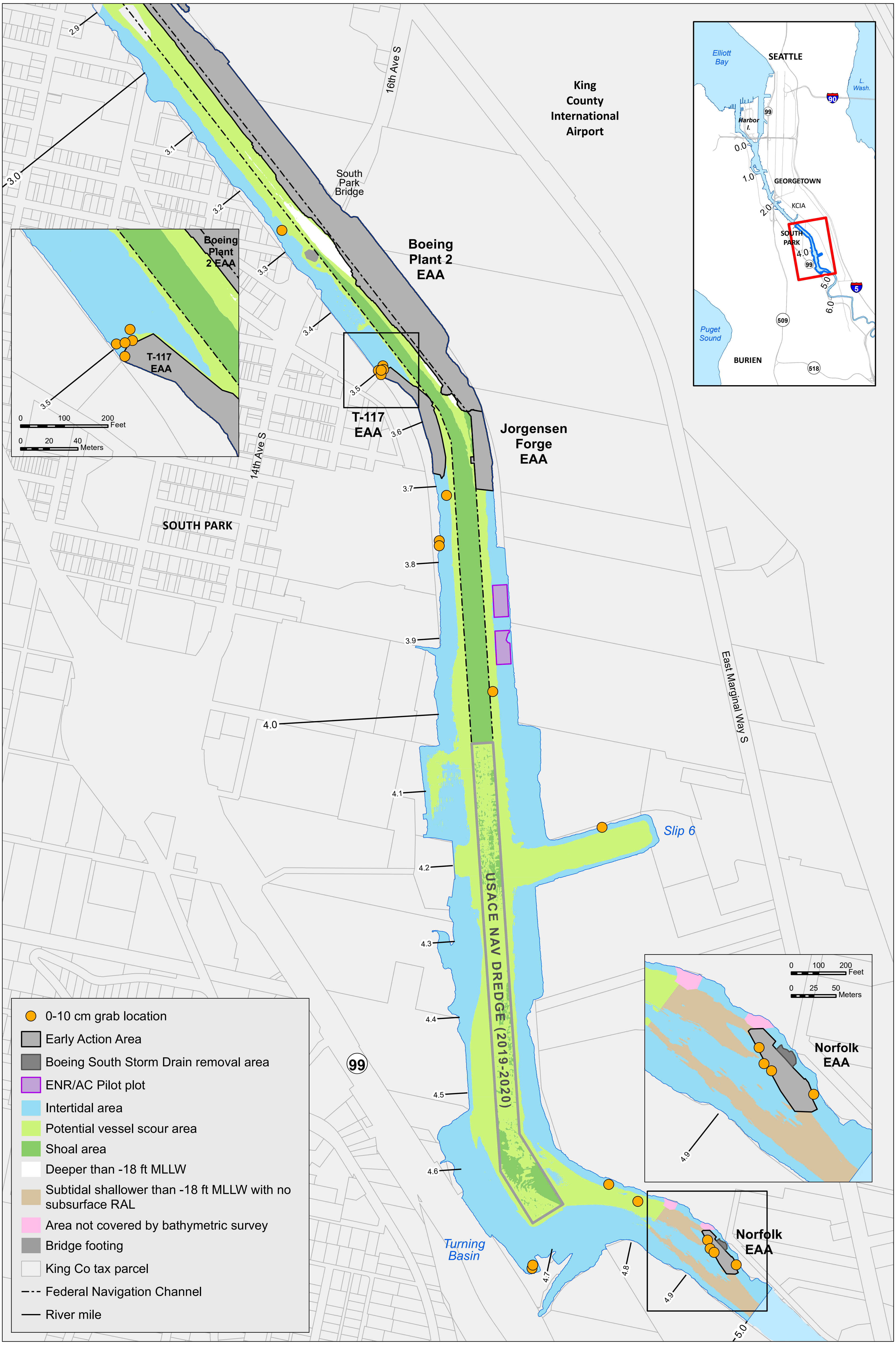

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Map A-2a. Phase III PDI surface sediment chemistry sample locations

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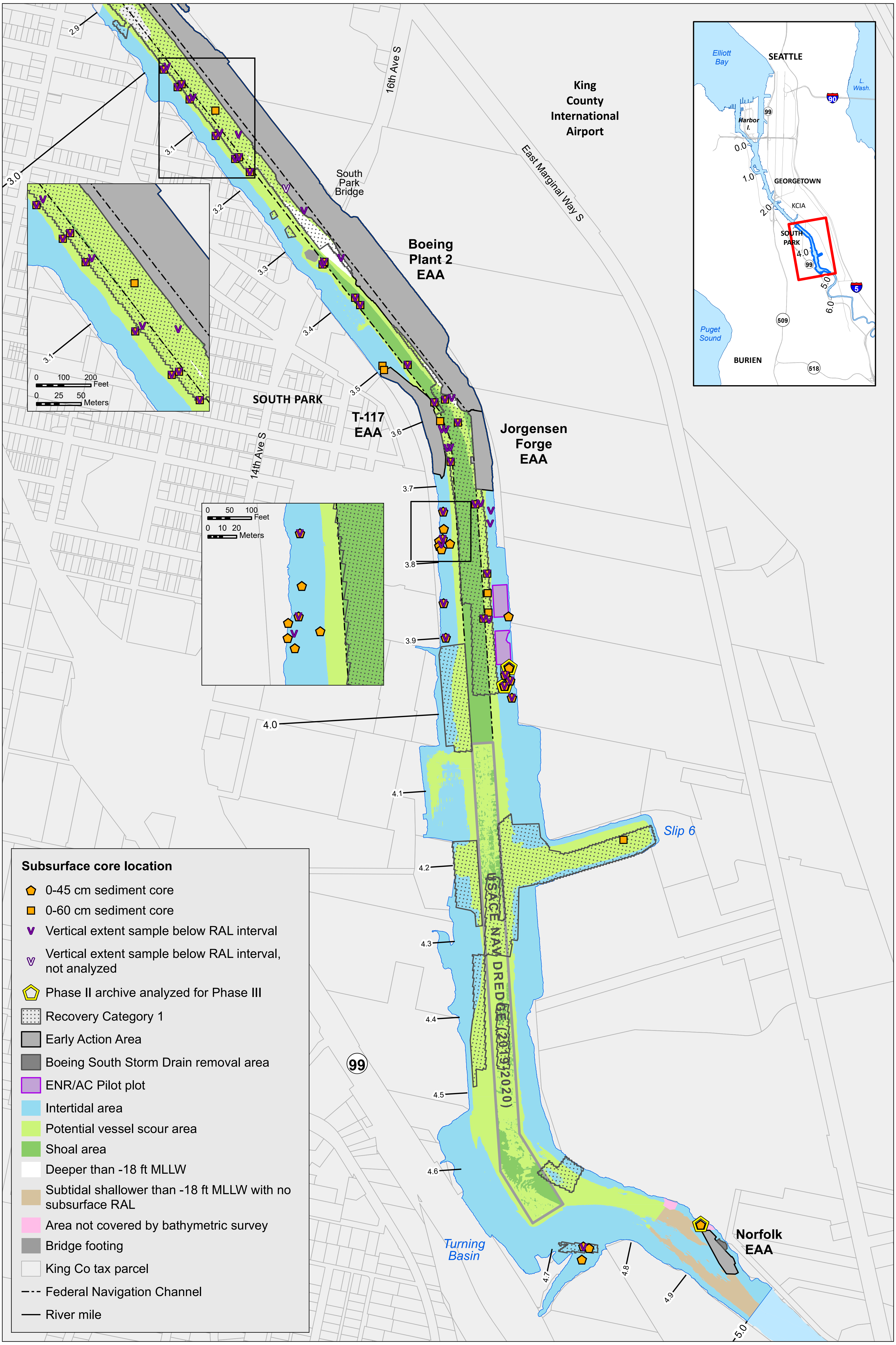
Prepared by nicolase, 11/2/2023; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Remedial Design\App A Phase III Data Report\Map A-2a 7234 Phase III PDI locations - surface.mxd



Prepared by nicolase, 10/26/2023; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Remedial Design\App A Phase III Data Report\Map A-2b 7234 Phase III PDI locations - subsurface.mxd

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N

0 500 1,000 Feet

0 200 400 Meters

Map A-2b. Phase III PDI subsurface sediment chemistry sample locations and intervals

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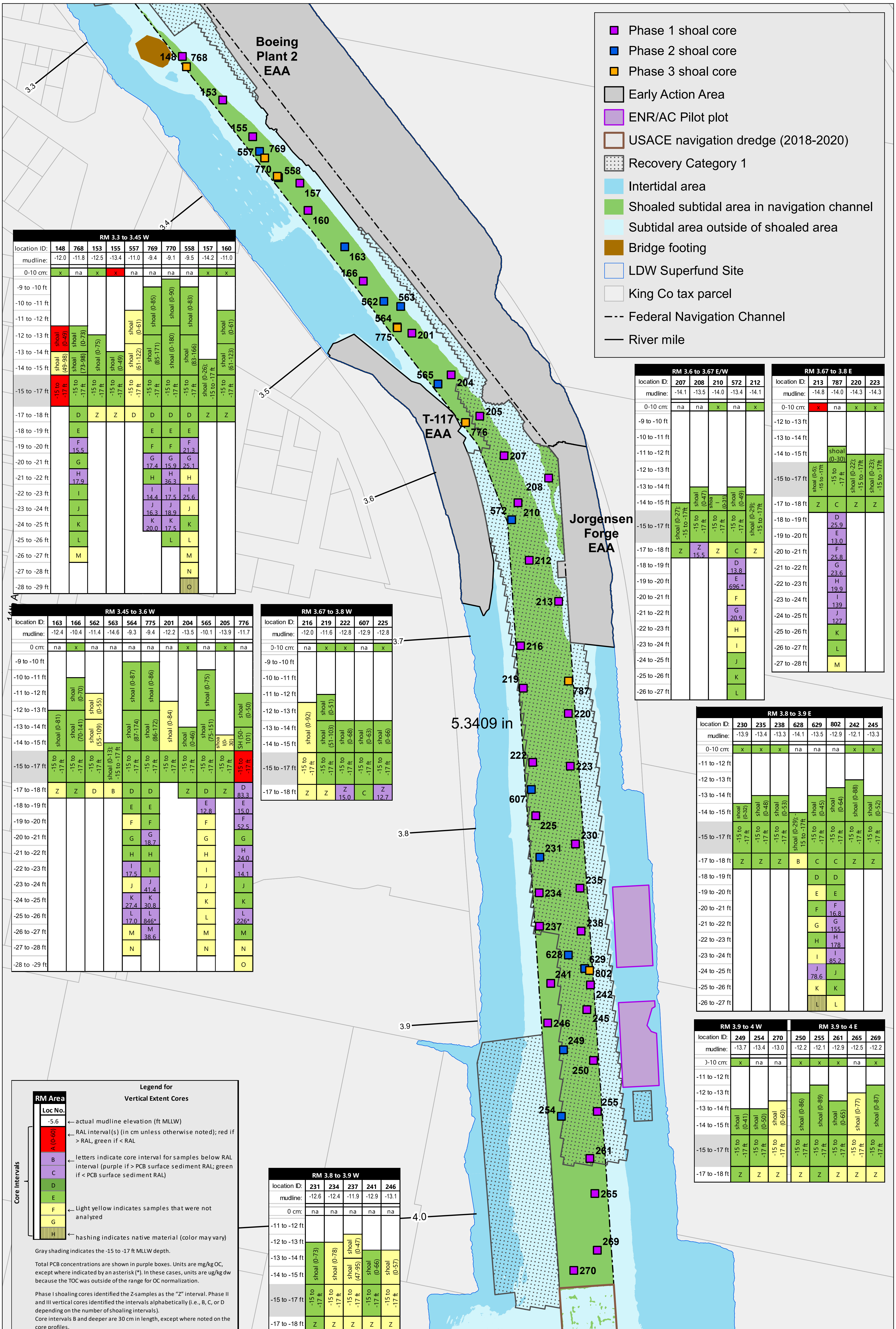

RM 3.3 to 3.45 W										
location ID:	148	768	153	155	557	769	770	558	157	160
mudline:	-12.0	-11.8	-12.5	-13.4	-11.0	-9.4	-9.1	-9.5	-14.2	-11.0
0-10 cm:	x	na	x	x	na	na	na	na	x	x
-9 to -10 ft										
-10 to -11 ft						shoal (0-85)	shoal (0-90)	shoal (0-83)		
-11 to -12 ft					shoal (0-61)					shoal (0-61)
-12 to -13 ft	shoal (0-49)	shoal (0-73)								
-13 to -14 ft			shoal (0-75)			shoal (85-171)	shoal (0-180)	shoal (83-166)		
-14 to -15 ft	shoal (49-98)	shoal (73-98)		shoal (0-49)	shoal (61-122)					shoal (61-123)
-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	shoal (0-26); -15 to -17 ft	-15 to -17 ft
-17 to -18 ft		D	Z	Z	D	D	D	D	Z	Z
-18 to -19 ft		E				E	E	E		
-19 to -20 ft		F 15.5				F	F	F 21.3		
-20 to -21 ft		G				G 17.4	G 15.9	G 25.1		
-21 to -22 ft		H 17.9				H	H 36.3	H		
-22 to -23 ft		I				I 14.4	I 17.5	I 25.6		
-23 to -24 ft		J				J 16.3	J 18.9	J		
-24 to -25 ft		K				K 20.0	K 17.5	K		
-25 to -26 ft		L					L	L		
-26 to -27 ft		M						M		
-27 to -28 ft								N		
-28 to -29 ft								O		

RM 3.45 to 3.6 W											
location ID:	163	166	562	563	564	775	201	204	565	205	776
mudline:	-12.4	-10.4	-11.4	-14.6	-9.3	-9.4	-12.2	-13.5	-10.1	-13.9	-11.7
0 cm:	na	x	na	na	na	na	na	x	na	x	na
-9 to -10 ft											
-10 to -11 ft					shoal (0-87)	shoal (0-86)					
-11 to -12 ft		shoal (0-70)							shoal (0-75)		
-12 to -13 ft			shoal (0-55)								shoal (0-50)
-13 to -14 ft	shoal (0-81)	shoal (70-141)			shoal (87-174)	shoal (86-172)	shoal (0-84)		shoal (75-151)		
-14 to -15 ft			shoal (55-109)					shoal (0-46)		shoa l(0-30)	SH (50-101)
-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	shoal (0-13); -15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft
-17 to -18 ft	Z	Z	D	B	D	D		Z	D	Z	D 83.3
-18 to -19 ft					E	E			E 12.8		E 15.0
-19 to -20 ft					F	F			F		F 52.5
-20 to -21 ft					G	G 18.7			G		G
-21 to -22 ft					H	H			H		H 24.0
-22 to -23 ft					I 17.5	I			I		I 14.1
-23 to -24 ft					J	J 41.4			J		J
-24 to -25 ft					K 27.4	K 30.8			K		K
-25 to -26 ft					L 17.0	L 846*			L		L 226*
-26 to -27 ft					M	M 38.6			M		M
-27 to -28 ft					N				N		N
-28 to -29 ft											O

RM 3.67 to 3.8 W					
location ID:	216	219	222	607	225
mudline:	-12.0	-11.6	-12.8	-12.9	-12.8
0-10 cm:	na	x	x	na	x
-9 to -10 ft					
-10 to -11 ft					
-11 to -12 ft					
-12 to -13 ft		shoal (0-51)			
-13 to -14 ft	shoal (0-92)				
-14 to -15 ft		shoal (51-103)	shoal (0-68)	shoal (0-63)	shoal (0-66)
-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft
-17 to -18 ft	Z	Z	Z 15.0	C	Z 12.7

RM 3.6 to 3.67 E/W					
location ID:	207	208	210	572	212
mudline:	-14.1	-13.5	-14.0	-13.4	-14.1
0-10 cm:	na	na	x	na	x
-9 to -10 ft					
-10 to -11 ft					
-11 to -12 ft					
-12 to -13 ft					
-13 to -14 ft					
-14 to -15 ft		shoal (0-47)	shoal (0-31)	shoal (0-49)	
-15 to -17 ft	shoal (0-27); -15 to -17ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	shoal (0-29); -15 to -17ft
-17 to -18 ft	Z	Z 15.5	Z	C	Z
-18 to -19 ft				D 13.8	
-19 to -20 ft				E 696 *	
-20 to -21 ft				F	
-21 to -22 ft				G 20.9	
-22 to -23 ft				H	
-23 to -24 ft				I	
-24 to -25 ft				J	
-25 to -26 ft				K	
-26 to -27 ft				L	

RM 3.67 to 3.8 E				
location ID:	213	787	220	223
mudline:	-14.8	-14.0	-14.3	-14.3
0-10 cm:	x	na	x	x
-12 to -13 ft				
-13 to -14 ft				
-14 to -15 ft		shoal (0-30)		
-15 to -17 ft	shoal (0-5); -15 to -17ft	-15 to -17 ft	shoal (0-22); -15 to -17ft	shoal (0-23); -15 to -17ft
-17 to -18 ft	Z	C	Z	Z
-18 to -19 ft		D 25.9		
-19 to -20 ft		E 13.0		
-20 to -21 ft		F 25.8		
-21 to -22 ft		G 23.6		
-22 to -23 ft		H 19.9		
-23 to -24 ft		I 139		
-24 to -25 ft		J 127		
-25 to -26 ft		K		
-26 to -27 ft		L		
-27 to -28 ft		M		

RM 3.8 to 3.9 E								
location ID:	230	235	238	628	629	802	242	245
mudline:	-13.9	-13.4	-13.3	-14.1	-13.5	-12.9	-12.1	-13.3
0-10 cm:	x	x	x	na	na	na	x	x
-11 to -12 ft								
-12 to -13 ft								
-13 to -14 ft							shoal (0-88)	
-14 to -15 ft	shoal (0-32)	shoal (0-48)	shoal (0-53)		shoal (0-45)	shoal (0-64)		shoal (0-52)
-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	shoal (0-29); -15 to -17ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft
-17 to -18 ft	Z	Z	Z	B	C	C	Z	Z
-18 to -19 ft					D	D		
-19 to -20 ft					E	E		
-20 to -21 ft					F	F 16.8		
-21 to -22 ft					G	G 155		
-22 to -23 ft					H	H 178		
-23 to -24 ft					I	I 85.2		
-24 to -25 ft					J 78.6	J		
-25 to -26 ft					K	K		
-26 to -27 ft					L	L		

RM 3.9 to 4 W				RM 3.9 to 4 E				
location ID:	249	254	270	250	255	261	265	269
mudline:	-13.7	-13.4	-13.0	-12.2	-12.1	-12.9	-12.5	-12.2
0-10 cm:	x	na	na	x	x	x	na	x
-11 to -12 ft								
-12 to -13 ft								
-13 to -14 ft				shoal (0-86)	shoal (0-89)		shoal (0-77)	shoal (0-87)
-14 to -15 ft	shoal (0-41)	shoal (0-50)	shoal (0-60)			shoal (0-65)		
-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft
-17 to -18 ft	Z	Z	Z	Z	Z	Z	Z	Z

RM 3.8 to 3.9 W					
location ID:	231	234	237	241	246
mudline:	-12.6	-12.4	-11.9	-12.9	-13.1
0 cm:	na	na	na	na	na
-11 to -12 ft					
-12 to -13 ft			shoal (0-47)		
-13 to -14 ft	shoal (0-73)	shoal (0-78)			
-14 to -15 ft			shoal (47-95)	shoal (0-66)	shoal (0-57)
-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft	-15 to -17 ft
-17 to -18 ft	Z	Z	Z	Z	Z

Legend for Vertical Extent Cores

RM Area	
Loc No.	
-5.6	← actual mudline elevation (ft MLLW)
A (0-60)	← RAL interval(s) (in cm unless otherwise noted); red if > RAL, green if < RAL
B	← letters indicate core interval for samples below RAL interval (purple if > PCB surface sediment RAL; green if < PCB surface sediment RAL)
C	
D	
E	
F	← Light yellow indicates samples that were not analyzed
G	
H	← hashing indicates native material (color may vary)

Core Intervals

Gray shading indicates the -15 to -17 ft MLLW depth.

Total PCB concentrations are shown in purple boxes. Units are mg/kg OC, except where indicated by an asterisk (*). In these cases, units are ug/kg dw because the TOC was outside of the range for OC normalization.

Phase I shoaling cores identified the Z-samples as the "Z" interval. Phase II and III vertical cores identified the intervals alphabetically (i.e., B, C, or D depending on the number of shoaling intervals).
Core intervals B and deeper are 30 cm in length, except where noted on the core profiles.

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N

0 200 400 Feet

0 50 100 Meters

Map A-3. PDI shoal sample chemistry locations and intervals

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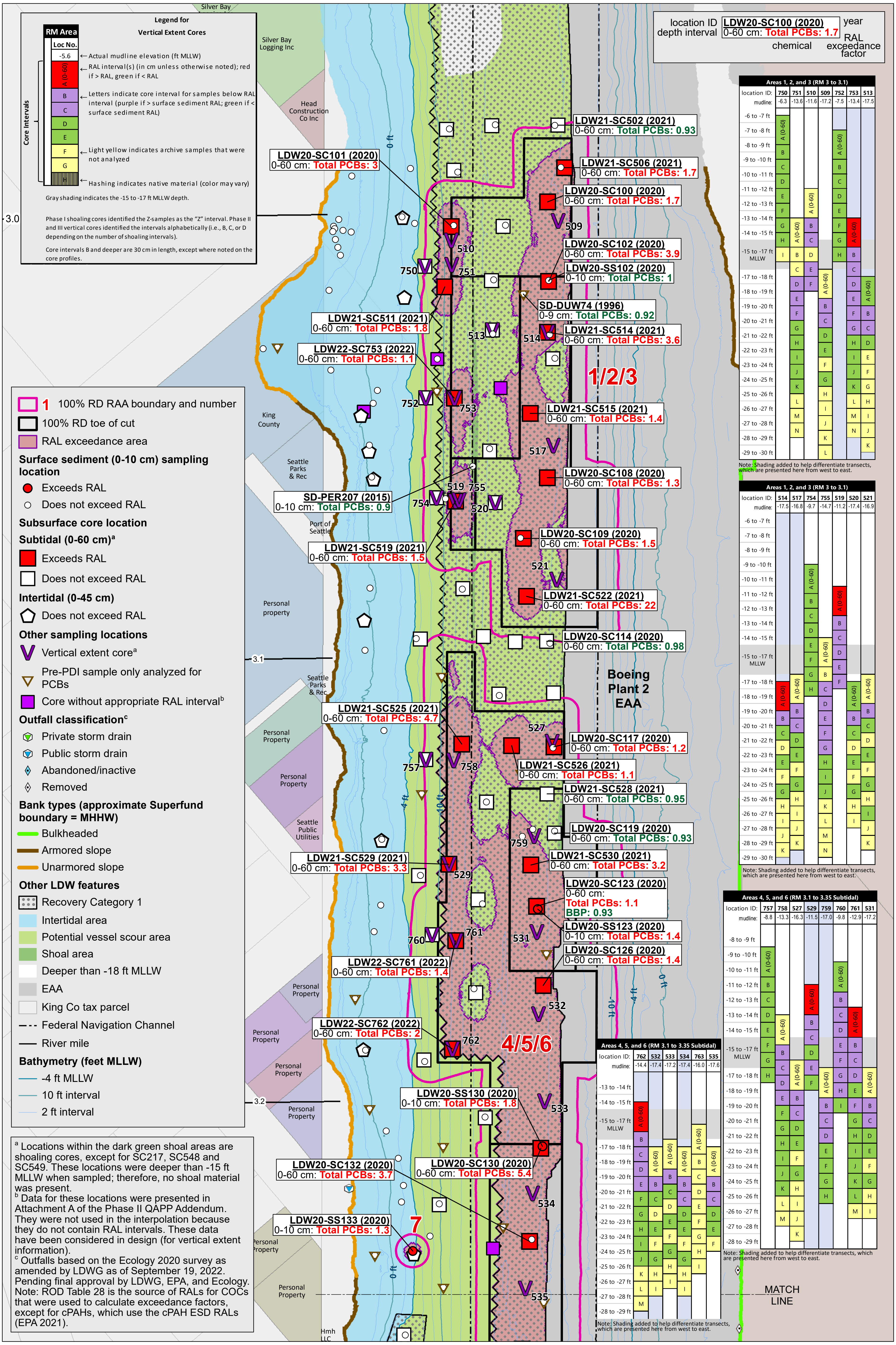
Prepared by nicolase, 10/26/2023; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Remedial Design\App A Phase III Data Report\Map A-3 7361 Shoaling cores.mxd



Prepared by craigh, 10/24/23; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Remedial Design\App A Phase III Data Report\Map A-4a 7172 Upper Reach Ph3 Design Data - RM 3.0-3.2.mxd

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Map A-4a. RAL exceedance areas from RM 3.0 to RM 3.2 with RAL exceedances and vertical extent data in the design dataset

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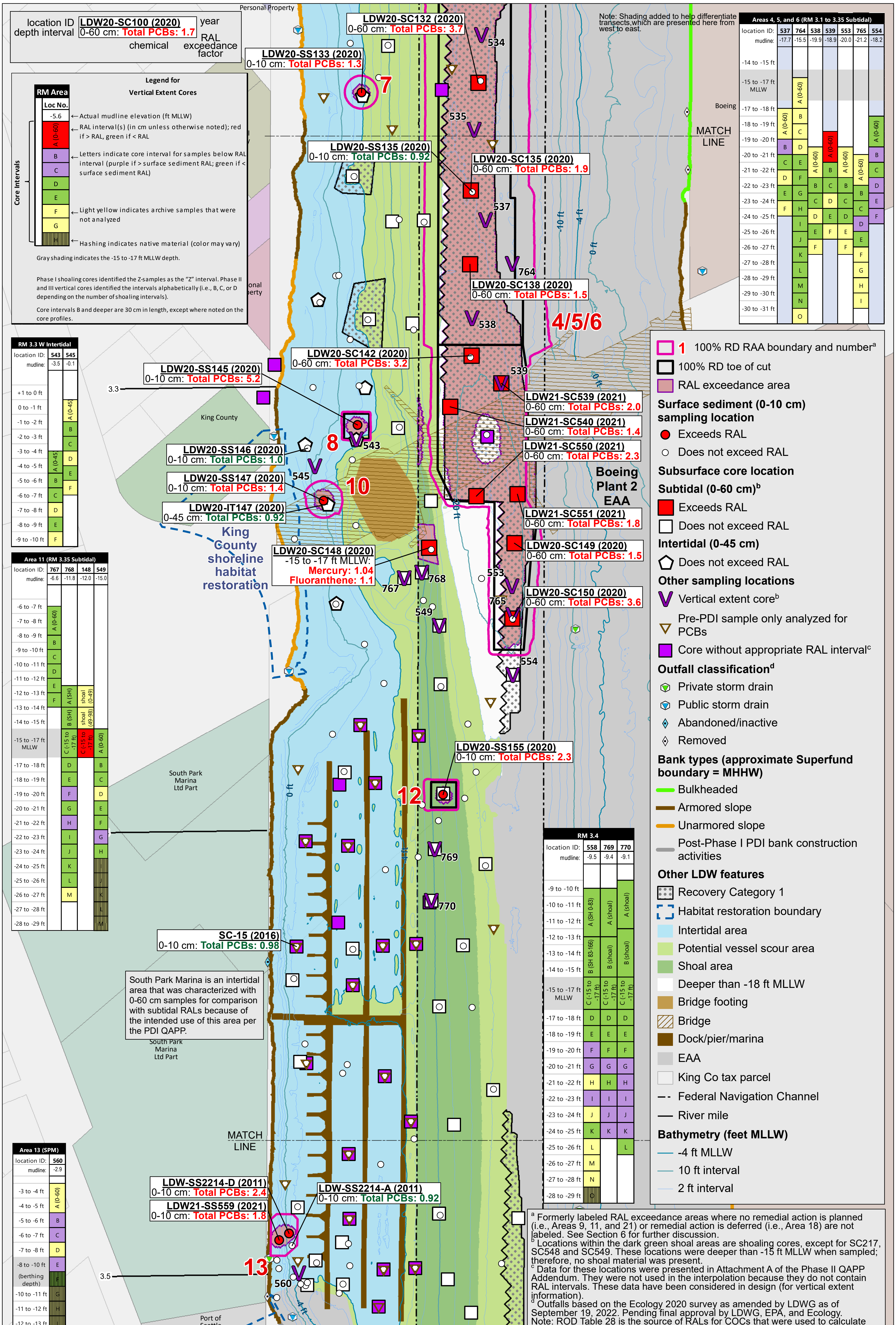

[a] Formerly labeled RAL exceedance areas where no remedial action is planned (i.e., Areas 9, 11, and 21) or remedial action is deferred (i.e., Area 18) are not labeled. See Section 6 for further discussion.

[b] Locations within the dark green shoal areas are shoaling cores, except for SC217, SC548 and SC549. These locations were deeper than -15 ft MLLW when sampled; therefore, no shoal material was present.

[c] Data for these locations were presented in Attachment A of the Phase II QAPP Addendum. They were not used in the interpolation because they do not contain RAL intervals. These data have been considered in design (for vertical extent information).

[d] Outfalls based on the Ecology 2020 survey as amended by LDWG as of September 19, 2022. Pending final approval by LDWG, EPA, and Ecology.

Note: ROD Table 28 is the source of RALs for COCs that were used to calculate exceedance factors, except for cPAHs, which use the cPAH ESD RALs (EPA 2021).

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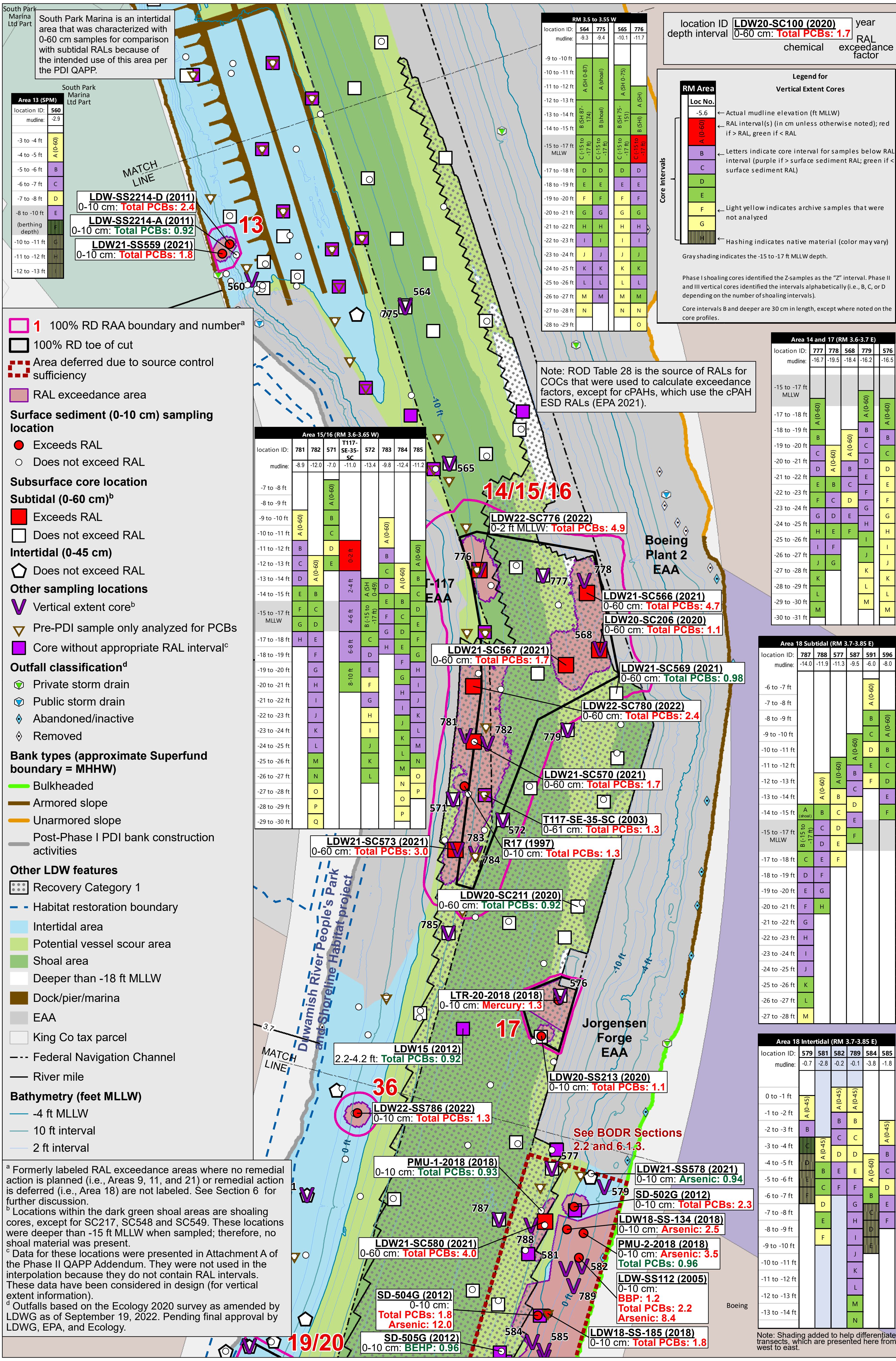
Map A-4b. RAL exceedance areas from RM 3.2 to RM 3.5 with RAL exceedances and vertical extent data in the design dataset.



[a] Formerly labeled RAL exceedance areas where no remedial action is planned (i.e., Areas 9, 11, and 21) or remedial action is deferred (i.e., Area 18) are not labeled. See Section 6 for further discussion.
[b] Locations within the dark green shoal areas are shoaling cores, except for SC217, SC548 and SC549. These locations were deeper than -15 ft MLLW when sampled; therefore, no shoal material was present.
[c] Data for these locations were presented in Attachment A of the Phase II QAPP Addendum. They were not used in the interpolation because they do not contain RAL intervals. These data have been considered in design (for vertical extent information).
[d] Outfalls based on the Ecology 2020 survey as amended by LDWG as of September 19, 2022. Pending final approval by LDWG, EPA, and Ecology.

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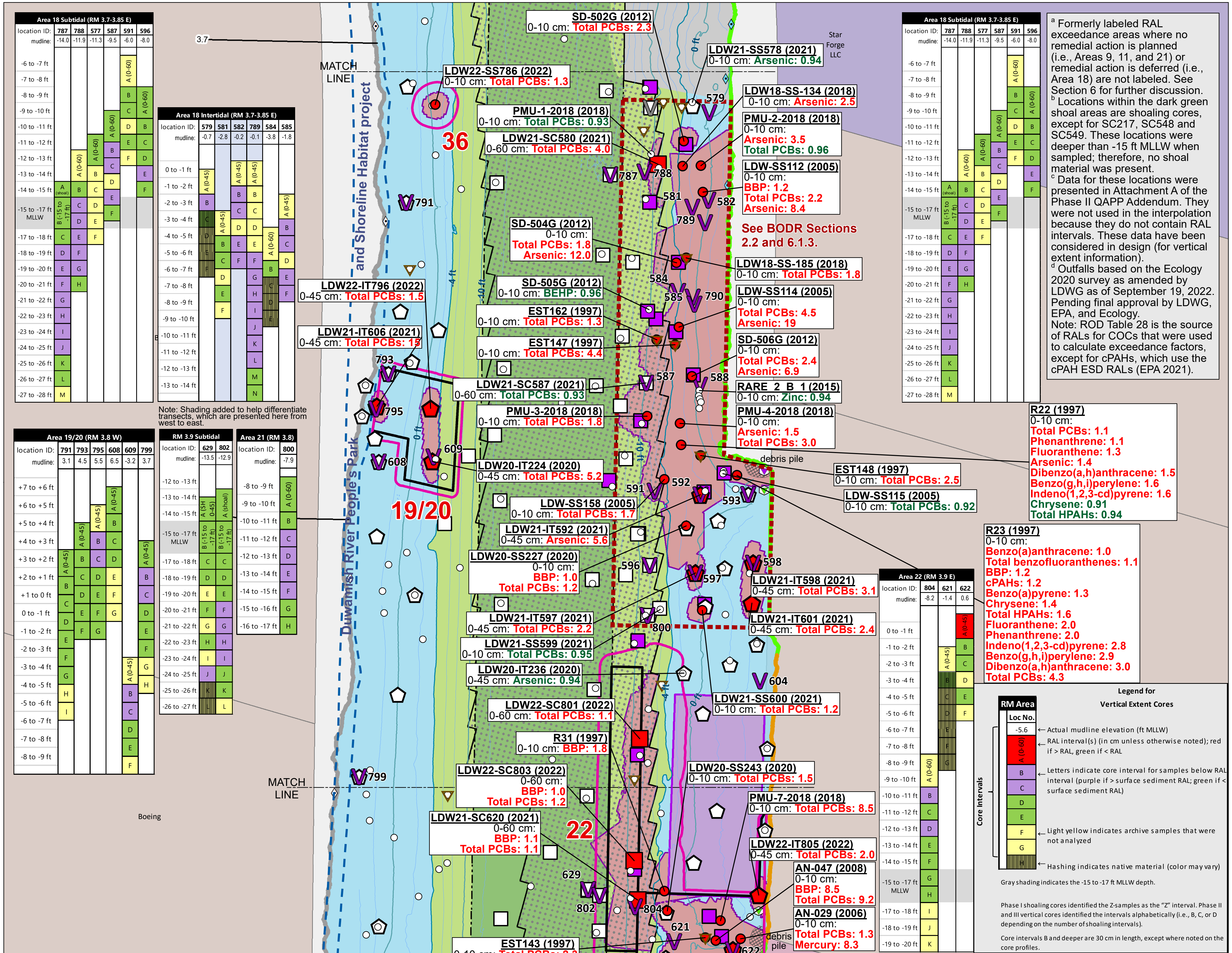
Map A-4c. RAL exceedance areas from RM 3.5 to RM 3.7 with RAL exceedances and vertical extent data in the design dataset

100% Remedial Design Basis of Design Report for the LDW Upper Reach — December 15, 2023

Prepared by craigh, 10/24/23; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Remedial Design\App A Phase III Data Report\Map A-4c 7172 Upper Reach Ph3 Design Data - RM 3.5-3.7.mxd



[a] Formerly labeled RAL exceedance areas where no remedial action is planned (i.e., Areas 9, 11, and 21) or remedial action is deferred (i.e., Area 18) are not labeled. See Section 6 for further discussion.
[b] Locations within the dark green shoal areas are shoaling cores, except for SC217, SC548 and SC549. These locations were deeper than -15 ft MLLW when sampled; therefore, no shoal material was present.
[c] Data for these locations were presented in Attachment A of the Phase II QAPP Addendum. They were not used in the interpolation because they do not contain RAL intervals. These data have been considered in design (for vertical extent information).
[d] Outfalls based on the Ecology 2020 survey as amended by LDWG as of September 19, 2022. Pending final approval by LDWG, EPA, and Ecology.
Note: ROD Table 28 is the source of RALs for COCs that were used to calculate exceedance factors, except for cPAHs, which use the cPAH ESD RALs (EPA 2021).

1 100% RD RAA boundary and number[a]
100% RD toe of cut
Area deferred due to source control sufficiency
RAL exceedance area

Surface sediment (0-10 cm) sampling location
- Exceeds RAL
- Does not exceed RAL

Subsurface core location

Subtidal (0-60 cm) [b]
- Exceeds RAL
- Does not exceed RAL

Intertidal (0-45 cm)
- Exceeds RAL
- Does not exceed RAL

Other sampling locations
- Vertical extent core[b]
- Vertical archive
- Pre-PDI sample only analyzed for PCBs
- Core without appropriate RAL interval[c]

Outfall classification[d]
- EOF/storm drain
- Private storm drain
- Abandoned/inactive
- Removed

Bank types (approximate Superfund boundary = MHHW)
- Bulkheaded
- Unarmored slope
- Post-Phase I PDI bank construction activities

Other LDW features
- Recovery Category 1
- Habitat restoration boundary
- Intertidal area
- Potential vessel scour area
- Shoal area
- EAA
- ENR/AC Pilot plot
- King Co tax parcel
- Federal Navigation Channel
- River mile

Bathymetry (feet MLLW)
- -4 ft MLLW
- 10 ft interval
- 2 ft interval

N
0 100 200 Feet
0 25 50 Meters

Map A-4d. RAL exceedance areas from RM 3.7 to RM 3.85 with RAL exceedances and vertical extent data in the design dataset

100% Remedial Design Basis of Design Report for the LDW Upper Reach DECEMBER 15, 2023

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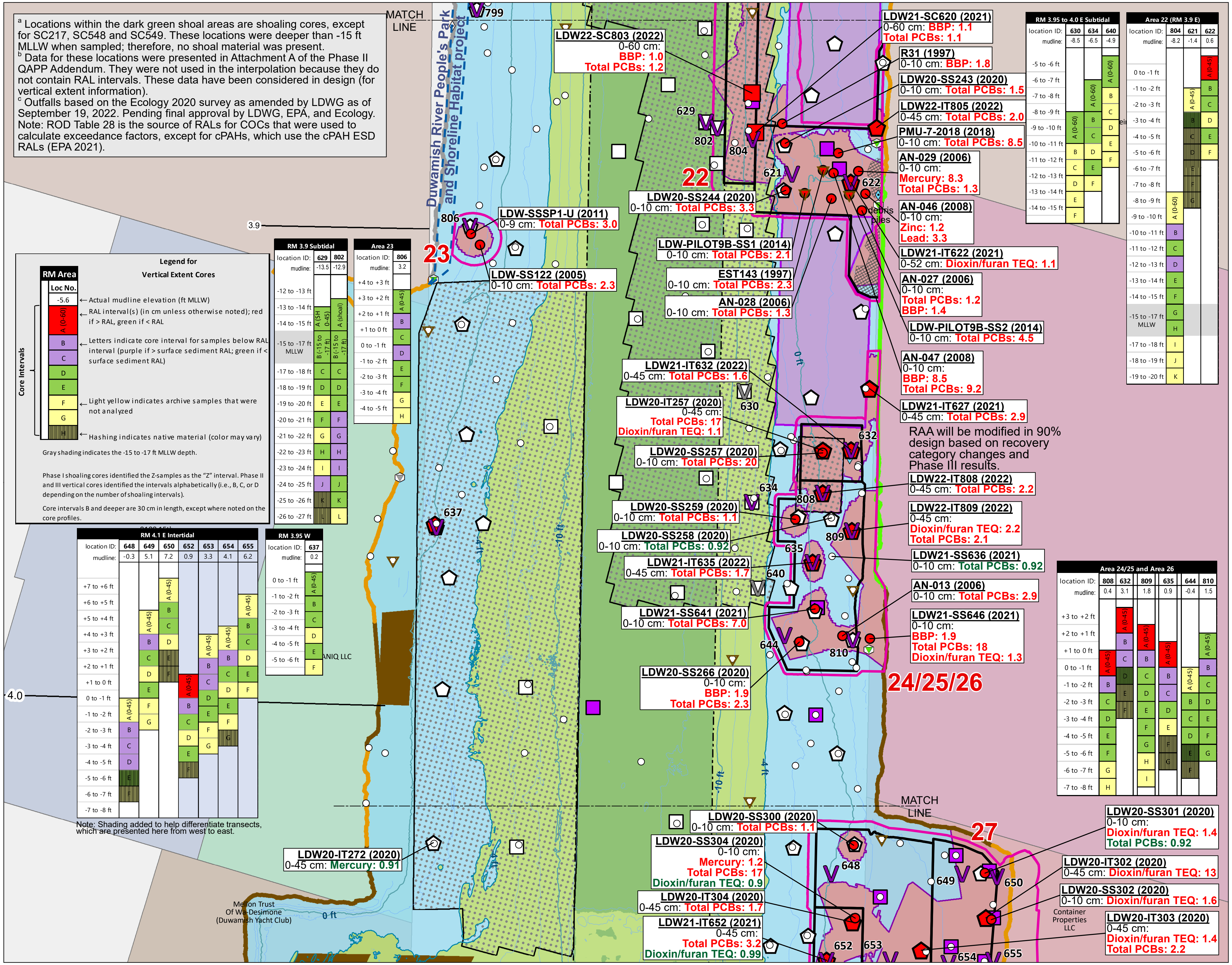

1 100% RD RAA boundary and number
100% RD toe of cut
RAL exceedance area

Surface sediment (0-10 cm) sampling location
- Exceeds RAL
- Does not exceed RAL

Subsurface core location

Subtidal (0-60 cm)[a]
- Exceeds RAL
- Does not exceed RAL

Intertidal (0-45 cm)
- Exceeds RAL
- Does not exceed RAL

Other sampling locations
- Vertical extent core[a]
- Vertical archive
- Pre-PDI sample only analyzed for PCBs
- Core without appropriate RAL interval[b]

Outfall classification[c]
- Private storm drain
- Stream, channel, or ditch
- Abandoned/inactive
- Removed
- Pipe of unresolved origin and/or use

Bank types (approximate Superfund boundary = MHHW)
- Bulkheaded
- Armored slope
- Unarmored slope
- Post-Phase I PDI bank construction activities

Other LDW features
- Recovery Category 1
- Habitat restoration boundary
- Intertidal area
- Potential vessel scour area
- Shoal area
- Dock/pier/marina
- ENR/AC Pilot plot
- King Co tax parcel
- Federal Navigation Channel
- River mile

Bathymetry (feet MLLW)
- -4 ft MLLW
- 10 ft interval
- 2 ft interval

N

0 100 200 Feet

0 25 50 Meters

Map A-4e. RAL exceedance areas from RM 3.85 to RM 4.05 with RAL exceedances and vertical extent data in the design dataset

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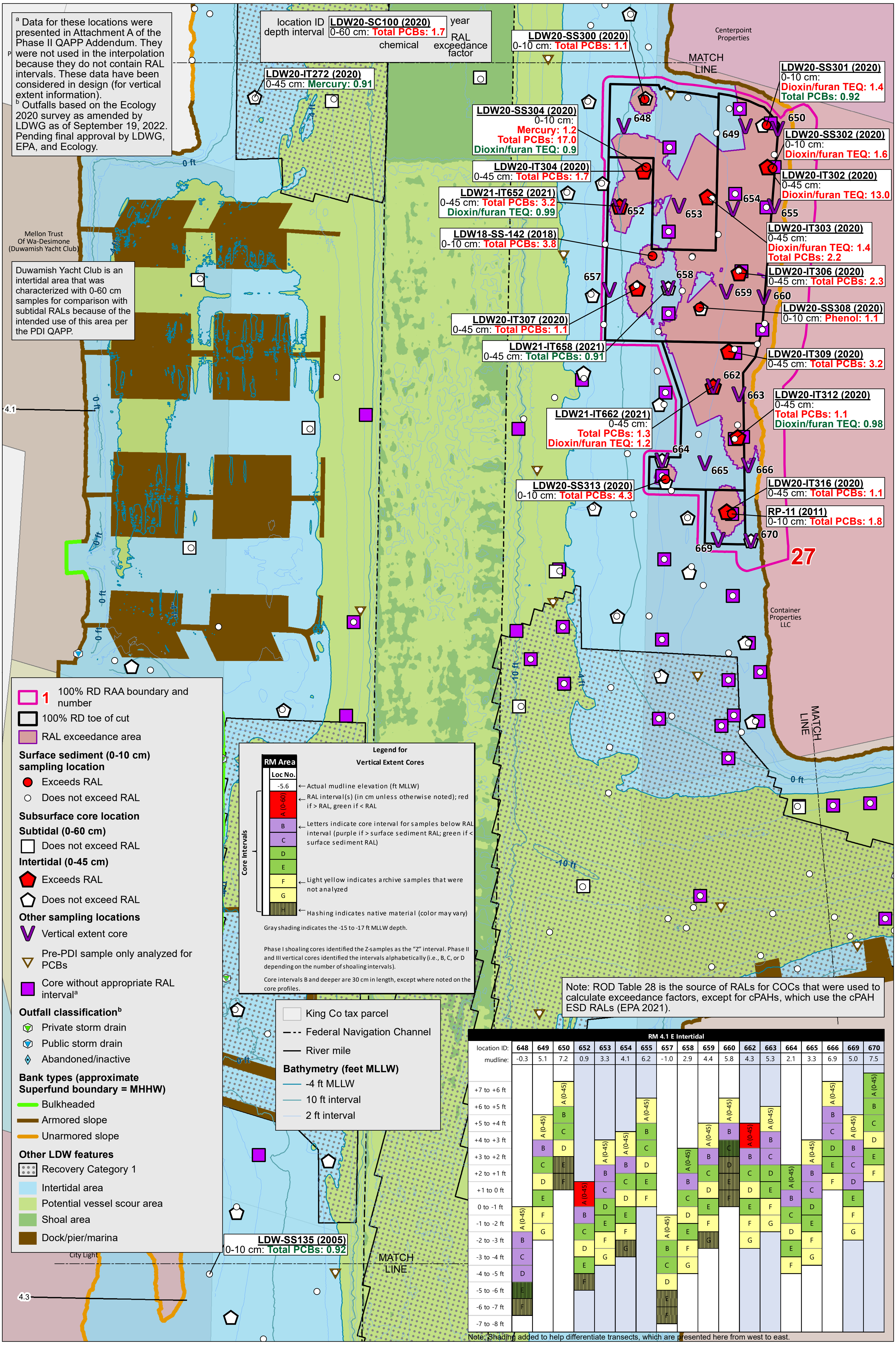

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N

0 100 200 Feet

0 25 50 Meters

Map A-4f. RAL exceedance areas from RM 4.05 to RM 4.3 with RAL exceedances and vertical extent data in the design dataset

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December 15, 2023

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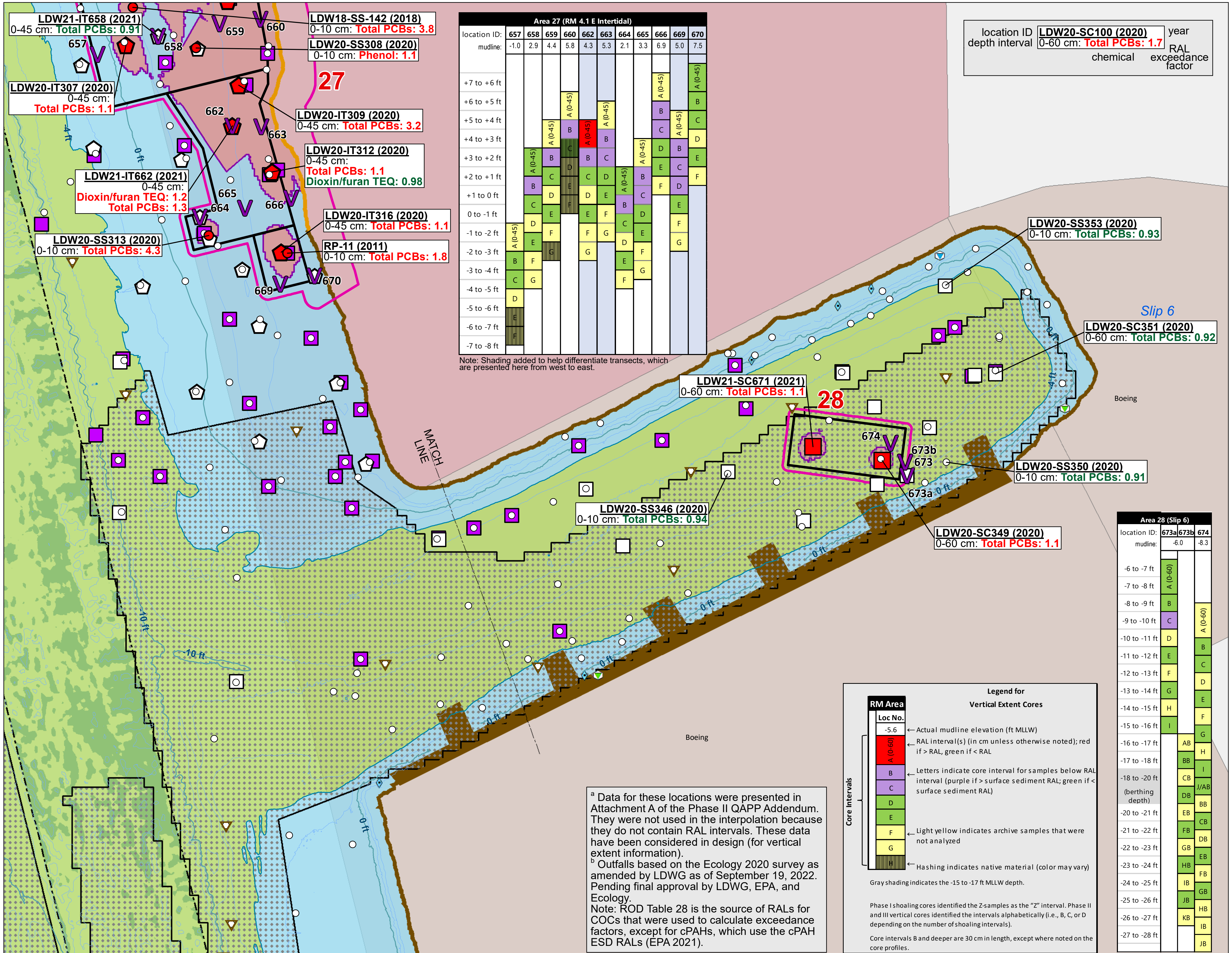

[a] Data for these locations were presented in Attachment A of the Phase II QAPP Addendum. They were not used in the interpolation because they do not contain RAL intervals. These data have been considered in design (for vertical extent information).
[b] Outfalls based on the Ecology 2020 survey as amended by LDWG as of September 19, 2022. Pending final approval by LDWG, EPA, and Ecology.
Note: ROD Table 28 is the source of RALs for COCs that were used to calculate exceedance factors, except for cPAHs, which use the cPAH ESD RALs (EPA 2021).

1 100% RD RAA boundary and number
100% RD toe of cut
RAL exceedance area
Surface sediment (0-10 cm) sampling location
- Exceeds RAL
- Does not exceed RAL

Subsurface core location
Subtidal (0-60 cm)
- Exceeds RAL
- Does not exceed RAL

Intertidal (0-45 cm)
- Exceeds RAL
- Does not exceed RAL

Other sampling locations
- Vertical extent core
- Pre-PDI sample only analyzed for PCBs
- Core without appropriate RAL interval[a]

Outfall classification[b]
- Private storm drain
- Public storm drain
- Abandoned/inactive

Bank types (approximate Superfund boundary = MHHW)
- Armored slope
- Unarmored slope

Other LDW features
- Recovery Category 1
- Intertidal area
- Potential vessel scour area
- Shoal area
- Dock/pier/marina
- King Co tax parcel
- Federal Navigation Channel

Bathymetry (feet MLLW)
- -4 ft MLLW
- 10 ft interval
- 2 ft interval

N
0 100 200 Feet
0 25 50 Meters

Map A-4g. RAL exceedance areas in Slip 6 with RAL exceedance and vertical extent data in the design dataset

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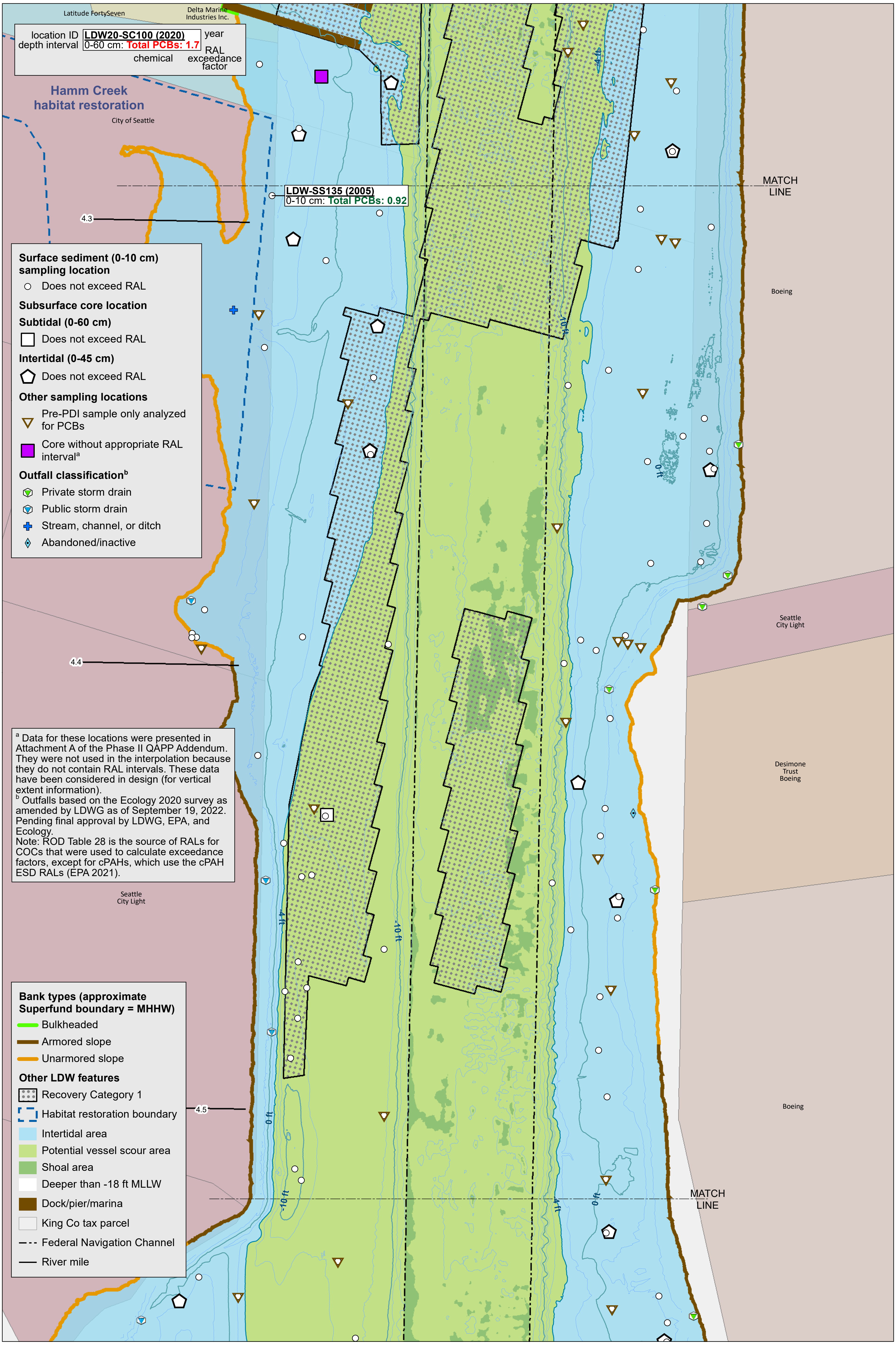

Map A-4h. RAL exceedance areas from RM 4.3 to RM 4.55 with RAL exceedances and vertical extent data in the design dataset

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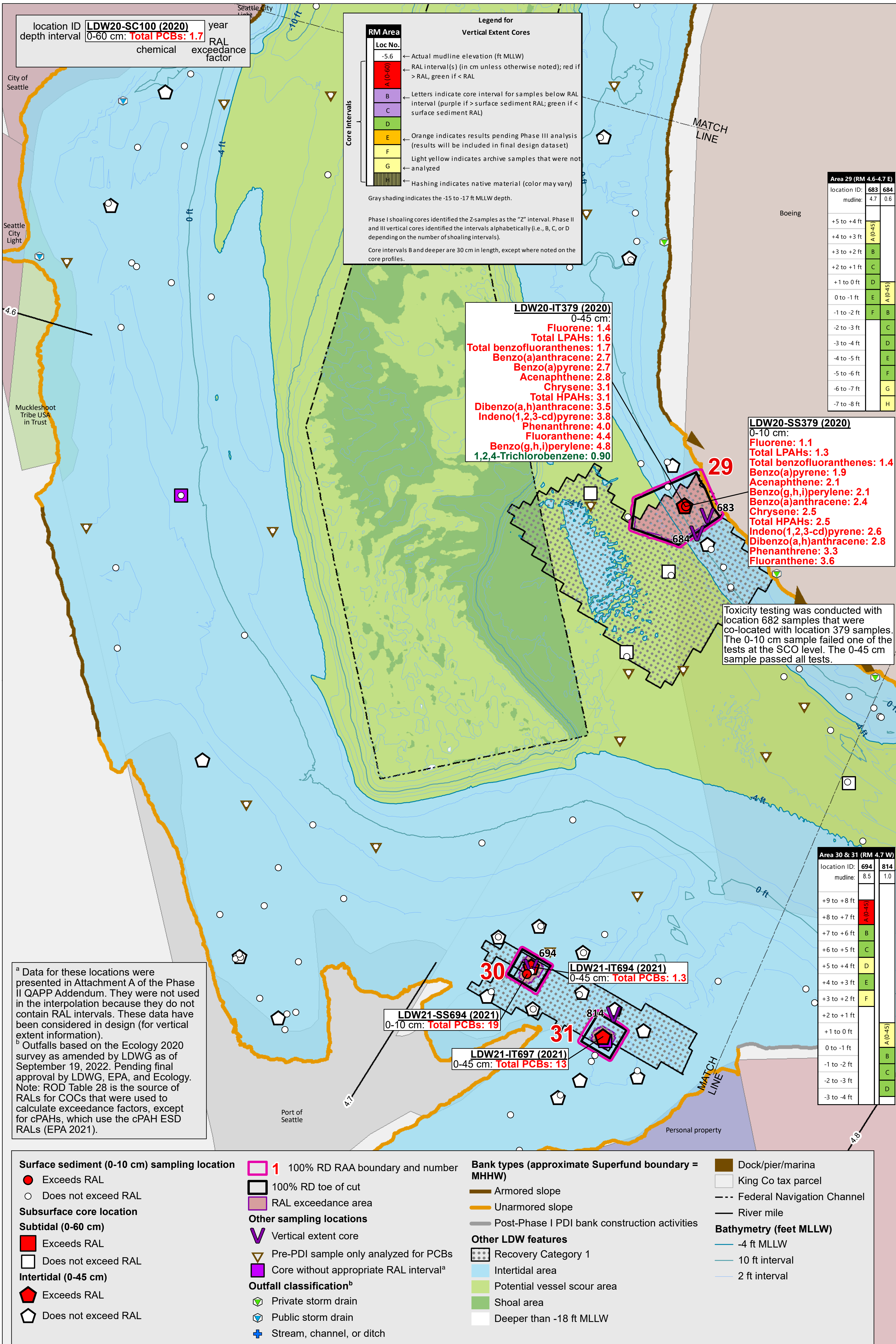

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Map A-4i. RAL exceedance areas from RM 4.55 to RM 4.8 with RAL exceedances and vertical extent data in the design dataset

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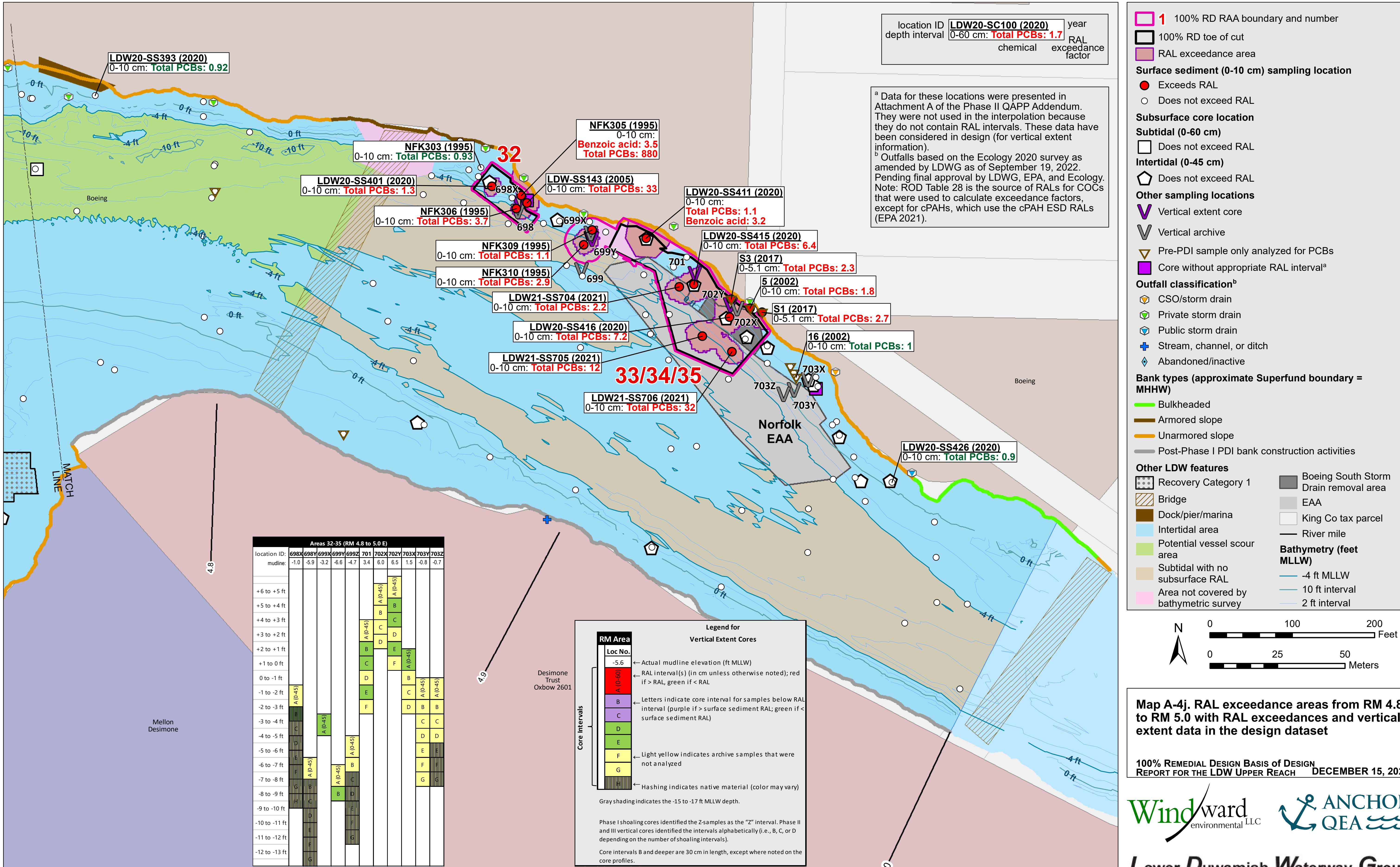

Map A-4j. RAL exceedance areas from RM 4.8 to RM 5.0 with RAL exceedances and vertical extent data in the design dataset

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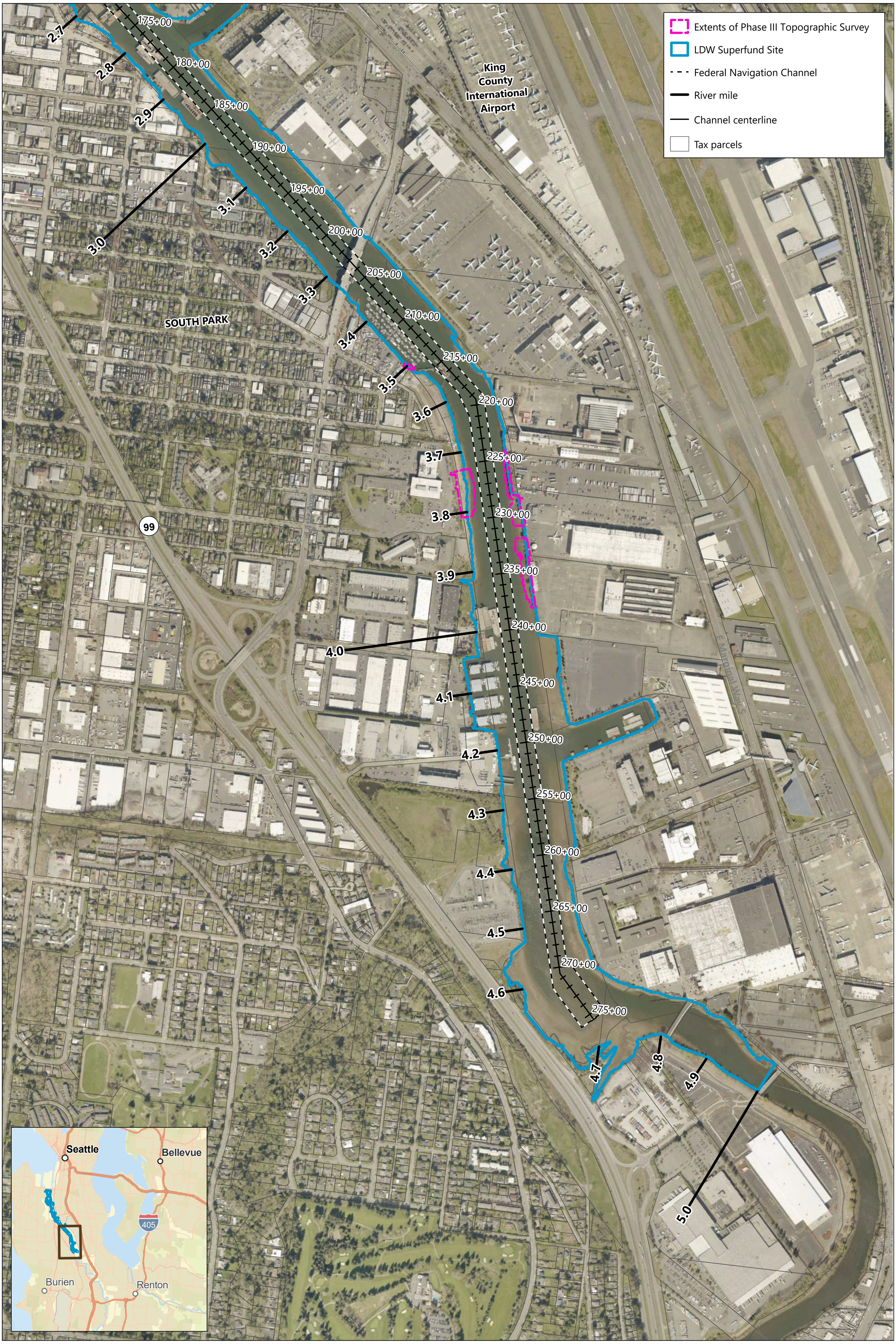

Prepared by jlarson, 5/15/2023; \\orcas\GIS\Jobs\KingCounty_0067\LDW\Maps\Reports\BasisDesignReport\LDW_BDR.aprx

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N

0 800 1,600 Feet

0 120 240 Meters

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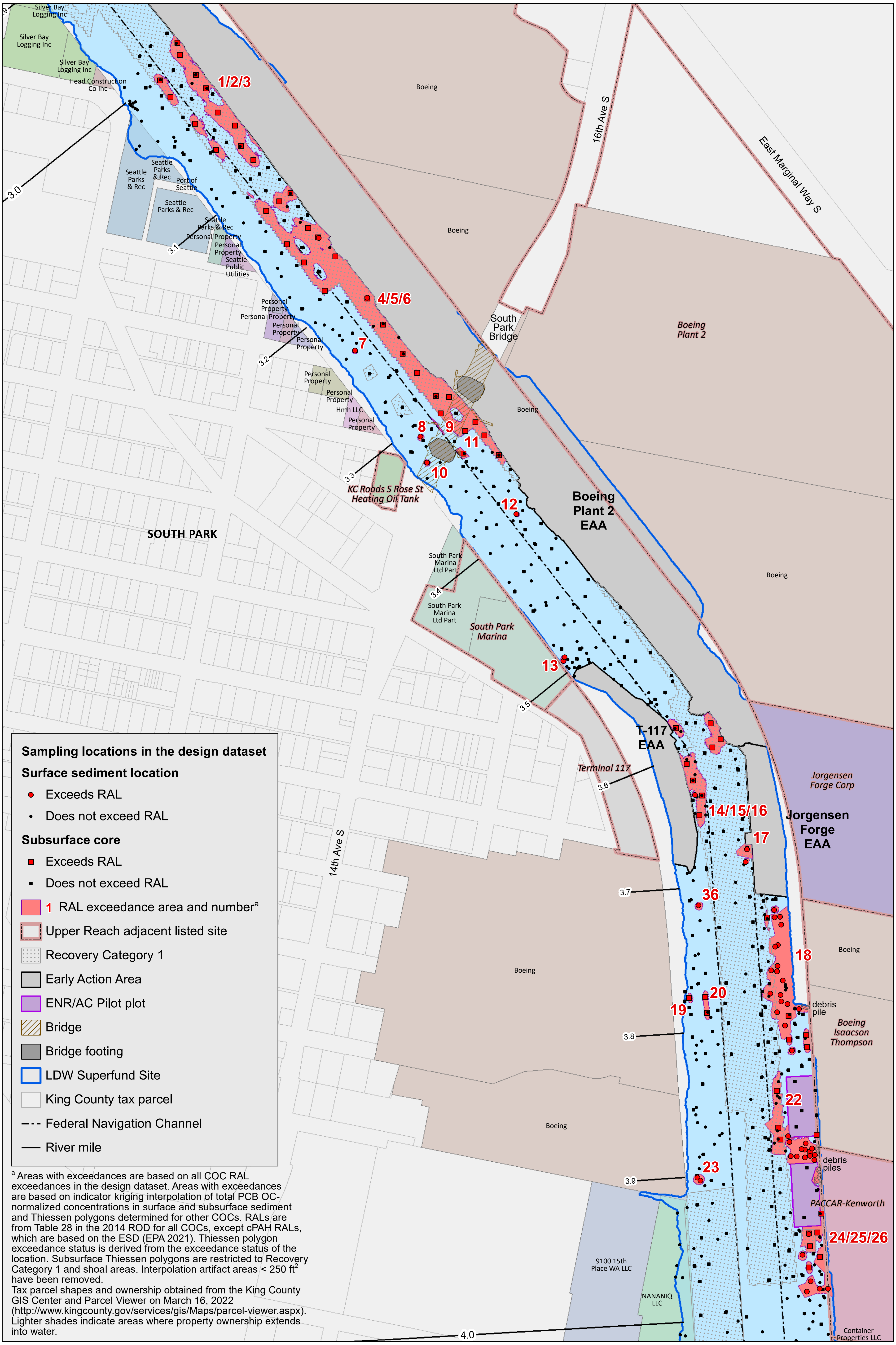
Map A-5. Topographic survey extents

100% Remedial Design Basis of Design Report for the LDW Upper Reach

DECEMBER 15, 2023



[a] Areas with exceedances are based on all COC RAL exceedances in the design dataset. Areas with exceedances are based on indicator kriging interpolation of total PCB OC-normalized concentrations in surface and subsurface sediment and Thiessen polygons determined for other COCs. RALs are from Table 28 in the 2014 ROD for all COCs, except cPAH RALs, which are based on the ESD (EPA 2021). Thiessen polygon exceedance status is derived from the exceedance status of the location. Subsurface Thiessen polygons are restricted to Recovery Category 1 and shoal areas. Interpolation artifact areas < 250 ft^2 have been removed.
Tax parcel shapes and ownership obtained from the King County GIS Center and Parcel Viewer on March 16, 2022 (http://www.kingcounty.gov/services/gis/Maps/parcel-viewer.aspx). Lighter shades indicate areas where property ownership extends into water.

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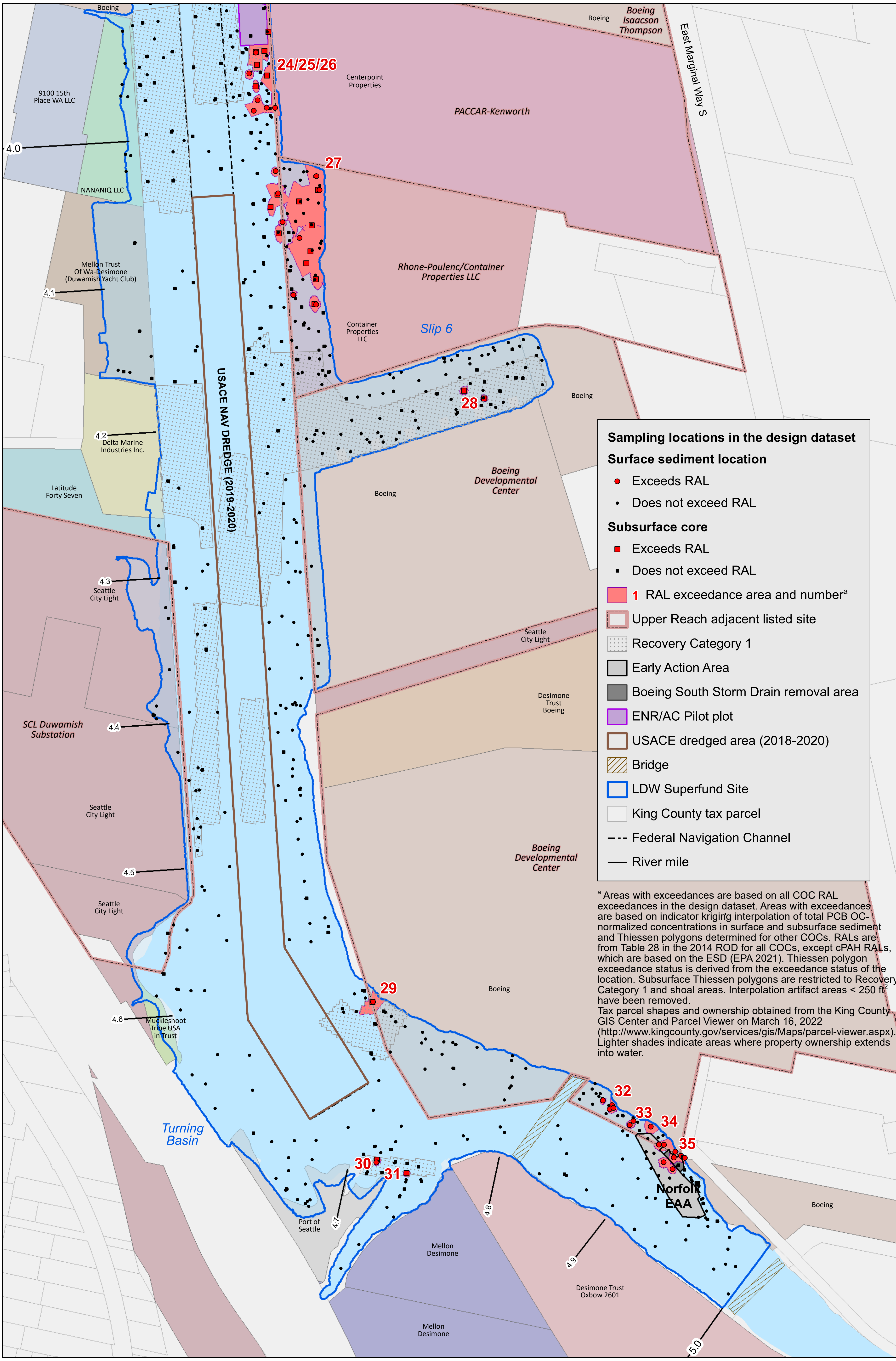
Map A-6a. RAL exceedance areas in the upper reach, RM 3.0 to RM 4.0

Prepared by craigh, 10/24/23; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Remedial Design\App A Phase III Data Report\Map A-6a 7259 Prelim RAL exceedance areas wPropOwnership RM 3-4.mxd



Prepared by craigh, 10/24/23; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Remedial Design\App A Phase III Data Report\Map A-6b 7259 Prelim RAL exceedance areas wPropOwnership RM 4-5.mxd

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Map A-6b. RAL exceedance areas in the upper reach, RM 4.0 to RM 5.0