Lower Duwamish Waterway Group

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

PRE-DESIGN STUDIES WORK PLAN

FINAL

Prepared for

Lower Duwamish Waterway Group

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Table of Contents

Tables

Figures

Maps

Acronyms

95UCL	95% upper confidence limit for the mean
AC	activated carbon
AOC	Administrative Order on Consent
ARAR	applicable or relevant and appropriate requirement
Axys	Axys Analytical Services, Ltd.
AWQC	ambient water quality criteria
BAZ	biologically active zone
BCM	bed composition model
BEHP	bis[2-ethylhexyl phthalate
BHC	benzene hexachloride
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
COC	contaminant of concern
COPC	contaminant of potential concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CPUE	catch per unit effort
CSM	conceptual site model
CSO	combined sewer overflow
CV	coefficient of variation
CWA	Clean Water Act
DDT	dichlorodiphenyltrichloroethane
DL	detection limit
DQO	data quality objective
DRCC	Duwamish River Cleanup Coalition
EAA	early action area
Ecology	Washington State Department of Ecology

EDL	estimated detection limit
EIM	Environmental Information Management
EPA	US Environmental Protection Agency
ENR	enhanced natural recovery
GIS	geographic information system
Integral	Integral Consulting Inc.
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LOE	line of evidence
MDD	minimum detectable difference
MHHW	mean higher high water
MIT	Massachusetts Institute of Technology
MLLW	mean lower low water
MNR	monitored natural recovery
MTCA	Model Toxics Control Act
NOAA	National Oceanic and Atmospheric Administration
ODEQ	Oregon Department of Environmental Quality
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
PE	polyethylene
PRC	performance reference compound
PVC	polyvinyl chloride
QC	quality control
QAPP	quality assurance project plan
RAL	remedial action level
RAO	remedial action objective
RARE	Regional Applied Research Effort
RI/FS	remedial investigation / feasibility study

RL	reporting limit
RM	river mile
RME	relative margin of error
ROD	Record of Decision
SCO	sediment cleanup objective
SIM	selective ion monitoring
SMS	Washington State Sediment Management Standards
SQS	sediment quality standards
STM	sediment transport model
SVOC	semivolatile organic compound
SWAC	spatially weighted average concentration
TAG	Technical Advisory Group
TBT	tributyltin
TEF	toxic equivalency factor
TEQ	toxic equivalent
TOC	total organic carbon
TTL	target tissue level
USACE	US Army Corps of Engineers
USGS	US Geological Survey
VOC	volatile organic compound
WAC	Washington Administrative Code
Windward	Windward Environmental LLC
WQC	water quality criteria

1 Introduction

In 2000, the City of Seattle, King County, the Port of Seattle, and The Boeing Company, working collectively as the Lower Duwamish Waterway Group (LDWG), agreed in an Administrative Order on Consent (AOC) to conduct a remedial investigation/feasibility study (RI/FS) for the Lower Duwamish Waterway (LDW) with oversight by the US Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology). In September 2001, the LDW was formally listed as a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund) site; in February 2002, the LDW was formally added to the National Priorities List as a Washington Model Toxics Control Act (MTCA) site. The RI was completed in 2010 (Windward 2010a) and the FS was completed in 2012 (AECOM 2012). A record of decision (ROD) was issued by EPA in 2014 (EPA 2014).

A third amendment to the AOC (EPA 2016) specified pre-design studies to "help EPA ensure that all remedial design data needs are addressed in the appropriate sequence and without delay" to advance the implementation of the ROD. This document is the work plan for the pre-design studies specified in the third amendment. Eleven tasks that are outlined in the third amendment are described herein. These tasks, including this work plan (Task 1), are:

- Task 1: Pre-design studies work plan
- Task 2: Existing data compilation
- Task 3: QAPPs and associated support documents
- Task 4: Sampling and analysis
- Task 5: Data reports
- Task 6: Data evaluation report
- Task 7: Waterway user survey and assessment of in-water structures work plan
- Task 8: Waterway user survey and assessment of in-water structures report
- Task 9: Recovery category recommendations
- Task 10: Design strategy recommendations report
- Task 11: Support for development of seafood consumption institutional controls

Task 11, support for development of seafood consumption institutional controls, is being addressed through an EPA-led process outside of the scope of this work plan. Thus, this task is not discussed further herein.

1.1 STUDY CONTEXT AND CONCEPTUAL SITE MODEL

The purpose of the pre-design studies, the context of proposed baseline sampling relative to other monitoring that will be conducted as part of the remedy, and the conceptual site model (CSM) are discussed in this section.

1.1.1 Purpose of pre-design studies

The 10 tasks that are described in this work plan are intended to fulfill the following objectives, as outlined in the third amendment (EPA 2016):

- Consistent with Section 13.2.3 of the ROD (EPA 2014), establish post-early action area (EAA) cleanup baseline conditions in environmental media, evaluate the effectiveness of EAA cleanups and the degree to which natural recovery has occurred since the RI/FS, establish baseline data for comparison to post-remedial action data, and aid in the evaluation of source control.
- Perform a survey of waterway users and an assessment of in-water structures to inform recovery category recommendations and technology assignments.
- Identify other site-wide and area-specific remedial design and remedial action information needs.
- Develop a strategy for remedial design phasing.

The scope of this work does not include the filling of area-specific design data needs, nor does it include duplication of characterization being conducted under MTCA at specific sites along the waterway.

1.1.2 Context within overall program

The pre-design studies described in this work plan are being conducted as a part of an ongoing process to address the site. This process has included an RI/FS (Windward 2010a; AECOM 2012) to study the site, to assess sources and risks to human health and the environment, and to evaluate cleanup alternatives. EPA's ROD outlined the sediment cleanup plan for the LDW. The next phases of the cleanup process include pre-design studies, remedial design, construction of the remedy, and monitoring of the remedy outcome. Source control actions in support of the cleanup have been underway and are ongoing. The pre-design studies described in this work plan constitute a subset of the data collection efforts that have been or will be conducted within the LDW.

Numerous data have been collected within the waterway to date. As part of the RI/FS-associated data compilation and collection (Windward 2010a; AECOM 2012), 3,359 sediment samples, 473 tissue samples, and 1,034 water samples (including porewater, surface water, and seep samples) were analyzed or compiled, encompassing the period from 1990 to 2010. In addition, 232 storm drain and combined sewer system source tracing solids were analyzed, encompassing the period from 2002 to 2007.

Since the RI/FS data were compiled and collected, additional data have been collected by various parties. As part of the Task 2 activities described in Section 3.1, LDWG has compiled[1] additional data for 1,434 sediment samples, 2 tissue samples, 162 water samples, 320 groundwater samples, 664 storm drain and combined sewer system source tracing solids samples, and 54 bank samples, encompassing the period from 2010 to 2016.

Following the pre-design studies described in this work plan, a considerable amount of detailed area-specific data will be collected during design, as part of construction, during post-construction, and during long-term monitoring. An overview of these sampling efforts is presented in Table 1-1.

Site-wide characterization to determine baseline conditions for remedial action objectives (RAOs) 1, 2, and 4[2] will be conducted under pre-design sampling. While the frequency and timing of long-term monitoring are not being determined as part of the pre-design studies, it is assumed that the baseline sampling approach outlined in this work plan[3] will be repeated in the future at appropriate intervals. Baseline data combined with long-term monitoring will allow trend analysis to assess progress toward compliance with cleanup goals. Area-specific monitored natural recovery (MNR) monitoring for RAO 3 compliance will be conducted as post-construction monitoring over a 10-year period to determine whether RAO 3 goals are achieved. Additional data collection efforts will be conducted in support of design and construction, as discussed further in Section 3.9. Appendix K of the FS (AECOM 2012) provides a conceptual overview of monitoring associated with remedy implementation and effectiveness over the long-term.

[1] These data were compiled as part of two data compilation memoranda submitted to EPA(Windward and Integral 2017b; Windward 2017c).

[2] RAO 1 pertains to risks from seafood ingestion (human health), RAO 2 is related to direct contact risks (human health), RAO 3 is related to risks to the benthic invertebrate community (ecological health), and RAO 4 pertains to risks to higher-trophic-level species (fish, crabs, birds, and mammals - ecological health).

[3] Future data may inform modifications to the approach; any changes would be coordinated with EPA.

Table 1-1. Overview of environmental sampling efforts by project phase

Sampling Type	Sampling by Project Phase				
	Pre-Design Studies Sampling[a]	**Design Sampling[a]**	**Construction Monitoring[a,b]**	**Post-Construction Monitoring[a,b]**	**Long-Term Monitoring[a,b]**
Baseline/ river-wide sampling	· 0–10 cm surface sediment (site wide for RAOs 1, 2, 4[c]) · 0–45 cm sediment (clamming and beach play area wide for RAO 2[c]) · Fish, crab, clam tissue (for RAO 1[c] and fish advisory) · Surface water (for water quality ARAR) · Porewater (for RAO 1[c])	na	na	na	· 0–10 cm surface sediment (site wide for RAOs 1, 2, 4[c]) · 0–45 cm sediment (clamming and beach play area wide for RAO 2[c]) · Fish, crab, clam tissue (for RAO 1[c] and fish advisory) · Surface water (for water quality ARAR)
Source control/other characterization sampling	· Bank sampling – soil source control · Near outfall sampling – outfall source control · Seeps – groundwater source control	source control sufficiency sampling as needed by various parties	na	possible recontamination monitoring at certain locations	none identified at this time.
Location-specific/ technology-specific sampling	none identified as time critical for predesign purposes (Section 3.9).	surface and subsurface sediment samples for: · Final technology assignments · Final boundaries of dredging, capping, ENR, MNR > SCO · Cap modeling and design, as needed	· Water quality monitoring · Confirmatory/ residual sediment sampling in dredge areas without backfill or in perimeter areas · Cap/ENR placement verification	· MNR > benthic SCO (RAO 3[c]) surface sediment monitoring over 10-year period (contingent actions if RAO 3[c] goals not achieved in reasonable timeframe) · ENR surface sediment monitoring over a defined period (contingent actions if > RALs (RAO 3[c] not met or maintained)	cap monitoring

[a] See Appendix D for a detailed summary of additional data/information to be gathered during this phase.

[b] Section 7.3.1 of the LDW FS (AECOM 2012) provides additional background regarding the general purpose and objectives for this monitoring activity.

[c] RAOs are defined as follows: 1 – seafood consumption (human health); 2 – direct contact (human health); 3 – benthic invertebrates (ecological); 4 – fish, crab, wildlife (ecological).

ARAR – applicable or relevant and appropriate requirement
ENR – enhanced natural recovery
FS – feasibility study
LDW – Lower Duwamish Waterway
na – not applicable
MNR – monitored natural recovery
RAL – remedial action level
RAO – remedial action objective
SCO – sediment cleanup objective

1.2 ROLES AND RESPONSIBILITIES

Many parties are participating in the pre-design studies being performed by LDWG and its contractors; EPA and its contractor the US Army Corps of Engineers (USACE) are providing oversight.

Windward Environmental LLC (Windward) is coordinating activities for LDWG (including managing the team of subcontractors) and leading the following tasks: work plan development (Task 1); data compilation and data management (Task 2); and baseline data study design, collection, reporting, and evaluation (Tasks 3 through 6). Terrastat Consulting Group is providing statistical analysis and study design support for these tasks. Sediment Solutions, Clearway Environmental, Greylock Consulting, Fain Environmental, and Ramboll Environ all play supporting roles.

Integral Consulting Inc. (Integral) is working with Moffett & Nichol and Convergent Pacific LLC to design and implement the waterway users survey and structures assessment (Tasks 7 and 8). Integral is also leading the development of recovery category recommendations (Task 9) and preparing the design strategy report (Task 10).

Ecology and LDW stakeholders (e.g., Tribes, Duwamish River Cleanup Coalition [DRCC] Technical Advisory Group (TAG), and the National Oceanic and Atmospheric Administration [NOAA]) are participating in the review of pre-design study deliverables and providing input in accordance with the review process established by EPA. In general, this process involves LDWG submitting draft deliverables to EPA, which shares these documents with stakeholders, soliciting comments. Stakeholder comments are submitted to EPA and shared with LDWG; EPA considers stakeholder comments for incorporation into EPA comments. LDWG then addresses EPA comments.

1.3 WORK PLAN ORGANIZATION

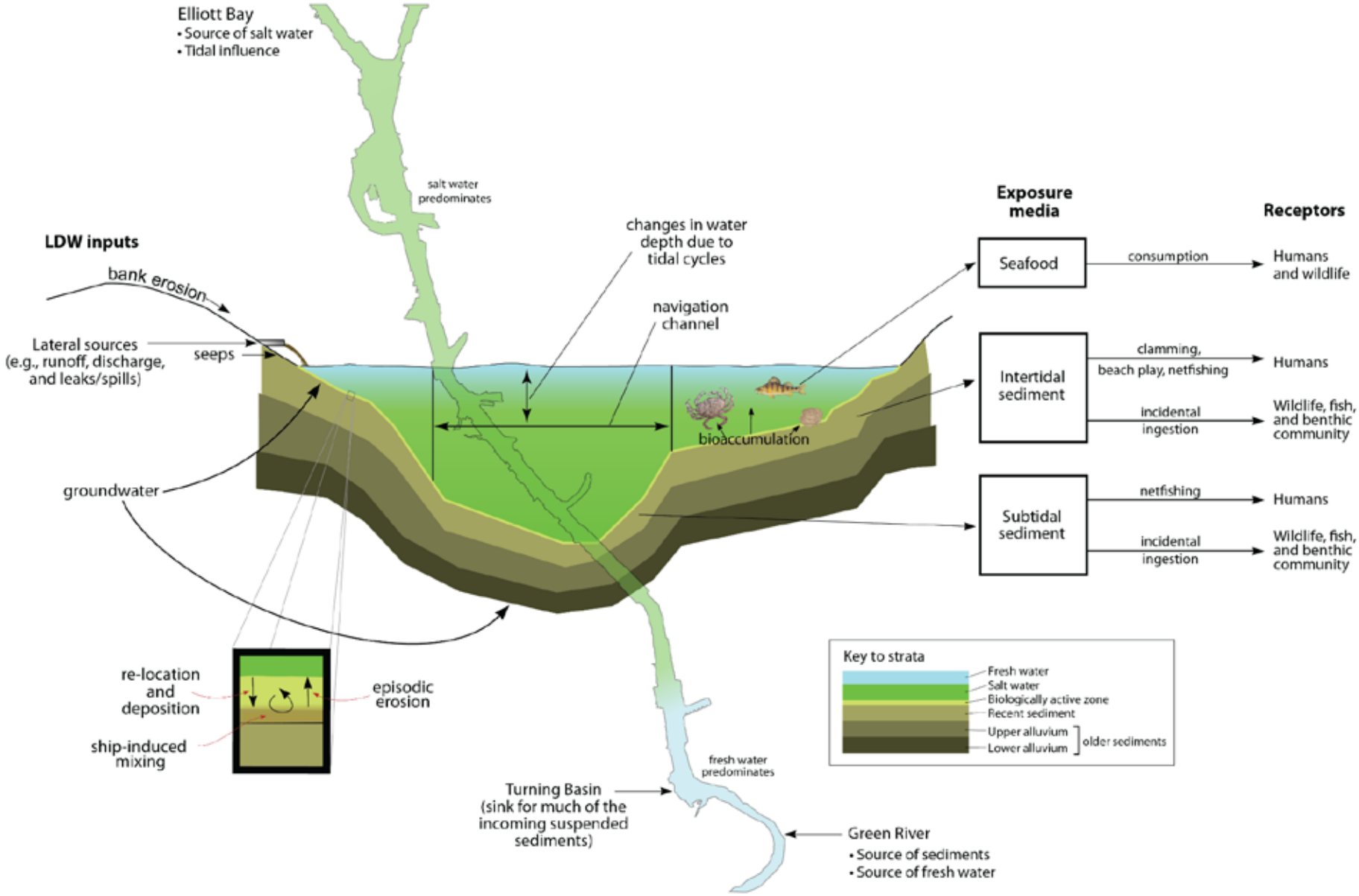
This work plan is divided into three sections. This section, Section 1, provides an introduction to the document. Section 2 provides a description of the CSM. Section 3 provides a summary of each task, including its purpose and approach. Section 4 presents a table summarizing the schedule and specified deliverables for each task.

Six appendices support this work plan. Appendix A contains the statistical support for the study designs, Appendix B presents selected analytical methods and reporting limits (RL), and Appendix C presents the data management plan. Appendix D provides a table that contains context for the pre-design studies, listing LDW data needs and timing considerations and specifying the effort whereby these data will be collected (e.g., enhanced natural recovery / activated carbon [ENR / AC] pilot study, pre-design studies, remediation design investigations and engineering, and remedial action). This summary-level information will be further developed in the Task 10 design strategy recommendations report to assist in the planning and sequencing of design data

acquisition. Appendix E contains the porewater addendum. Appendix F contains the results of the cPAH analysis of clam siphon skin.

2 Conceptual site model

The CSM for the LDW describes how the system functions, provides an overview of the major processes affecting the distribution and movement of contaminants at the site, and describes the exposure pathways (primarily consumption of contaminated seafood and direct contact with sediment) by which people and animals can be exposed to these contaminants (Figure 2-1). This information is helpful in developing study designs to assess the baseline conditions that will form the foundation for long-term monitoring of the LDW.



Note: Adapted from figure developed as part of the LDW RI (Windward 2010a).

Figure 2-1. Conceptual site model for exposure pathways and physical processes in the LDW

2.1 ENVIRONMENTAL SETTING

The in-water portion of the LDW, which extends from river mile (RM) 0 to RM 5.0, was modified in the early 1900s; the river was converted from a natural estuary to a straightened waterway that could better accommodate commercial traffic. Since that time, the central portion of the river (up to the turning basin at RM 4.7) has been dredged to maintain sufficient depths for navigation. Today, USACE generally performs maintenance dredging in the turning basin and in a nearby portion of the navigation channel every 1 to 3 years (EPA 2014). Dredging in other portions of the navigation channel occurs as needed to maintain the authorized navigation depth. The federal navigation channel exists down the center of the LDW; subtidal areas border the navigation channel, and shallow intertidal bench areas exist along the shoreline (AECOM 2012). The shoreline, or bank, of the waterway is comprised of approximately 88% steepened hard surfaces (e.g., riprap, sheet piling walls, and bulkheads), 0.7% concrete boat ramps, and approximately 11% more gently sloped beach and intertidal areas that remain throughout the waterway.

2.2 PHYSICAL PROCESSES

This section describes the physical characteristics of the LDW, both for surface water and sediment.

2.2.1 Surface water

As discussed in Section 2.7 of the LDW RI (Windward 2010a) and in Section 2.3 of the LDW FS (AECOM 2012), the LDW is an estuarine system with a well-stratified salt wedge that is influenced by freshwater flowing into the LDW from the Green River upstream and a tidal influx of saltwater from Elliott Bay. As is typical of tidally influenced estuaries, the LDW has a well-defined interface (i.e., limited mixing occurs) between the freshwater moving downstream and the tidally influenced saltwater wedge that sits at the bottom of the waterway (AECOM 2012; Windward 2010a). The upstream extent of this salt wedge is dependent on tidal and flow conditions. Based on the physical characteristics of the LDW and the processes governing the movement of water and sediment, the waterway has been divided into three reaches (AECOM 2012; Windward 2010a):

- **Reach 1: RM 0.0 to RM 2.2** – The salt wedge is always present in the lower reach of the LDW, although the toe of the wedge (i.e., the upstream-most extent) can recede as low as RM 1.8 during high flows during spring ebb tides. The salt wedge provides a protective barrier for the sediment in this reach, meaning bottom velocities that can scour occur relatively infrequently. Sedimentation rates, which are discussed in Section 2.2.2, are variable, although both the navigation channel and intertidal portions of this reach are net depositional.
- **Reach 2: RM 2.2 to RM 4.0 –** The salt wedge is generally present in this middle reach, except during high flows, when the toe of the wedge is often downstream

of this reach during ebb tides. As discussed in Section 2.2.2, sedimentation rates are variable and although some scour can occur, this reach is net depositional on an annual timescale.

- **Reach 3: RM 4.0 to RM 5.0** – The characteristics of this portion of the LDW are generally similar to those of a freshwater river, although the toe of the salt wedge can extend into and upstream of this reach during low and average flows. While this reach is net depositional on an annual scale, erosional events can occur periodically due to the higher flows and absence of the salt wedge in this upper portion of the LDW.

To illustrate the movement of the salt wedge in the LDW, Figure 2-2 shows the location of the salt wedge during both a low and high tide under specific river conditions (i.e., high upstream-flow conditions and spring tide). In this figure, the salinity gradient is shown from most saline (purple) to least saline (white). The purple layer at the bottom of the LDW represents unmixed saline water (which is the densest), with an upward progression to less saline water in the blue layer (which is less dense) as mixing occurs between the two layers. The white surface layer represents freshwater inflow from the Green River.

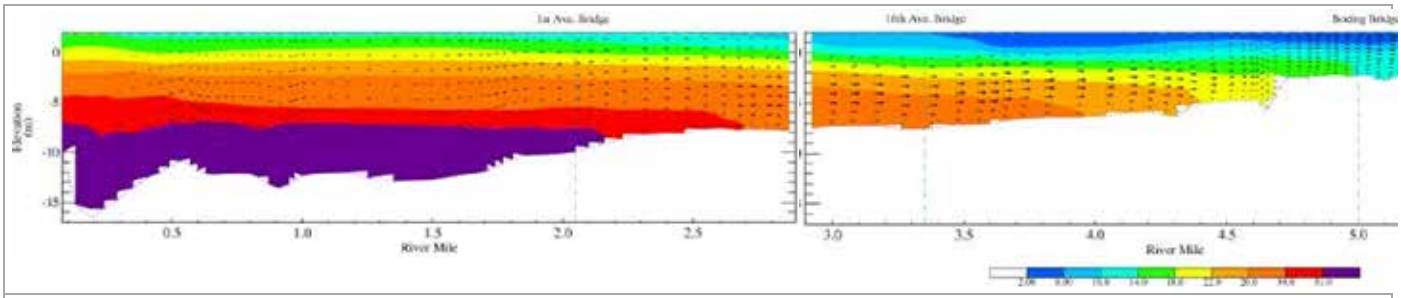


Figure A. Mean flow, high tide, and large extent of salt-water wedge

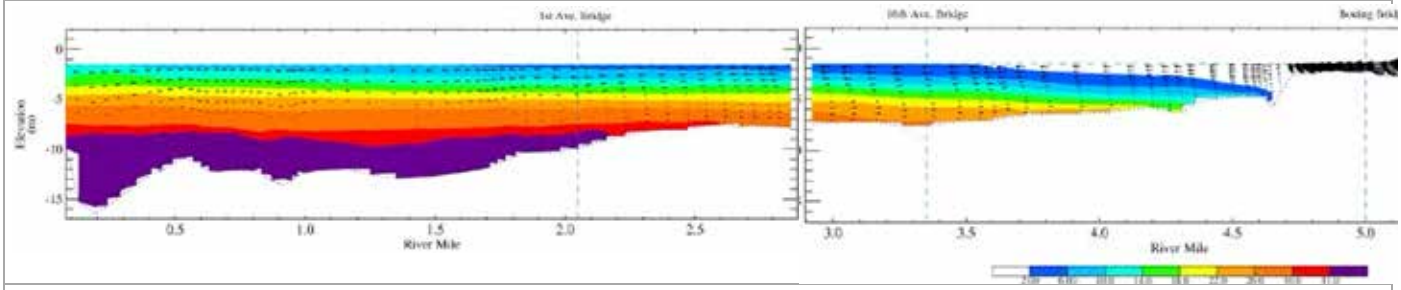


Figure B. Mean flow, low tide, and moderate/large extent of salt-water wedge

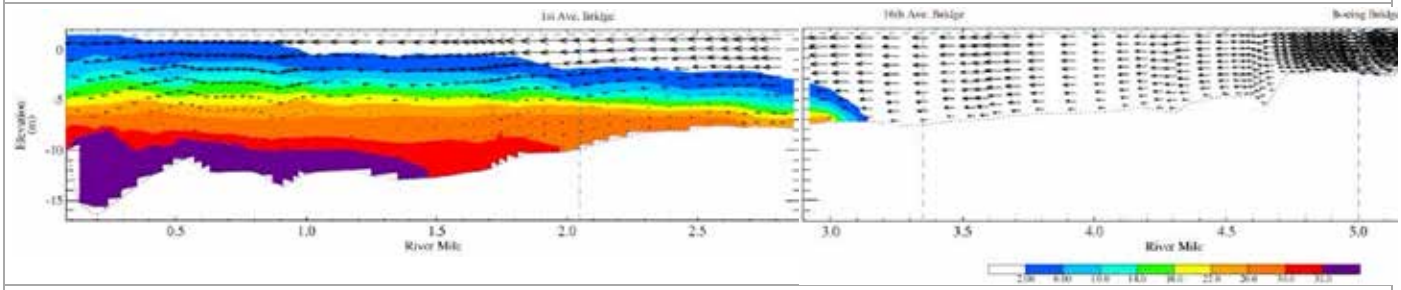


Figure C. 100 year high-flow event, high tide, and moderate/small extent of salt-water wedge

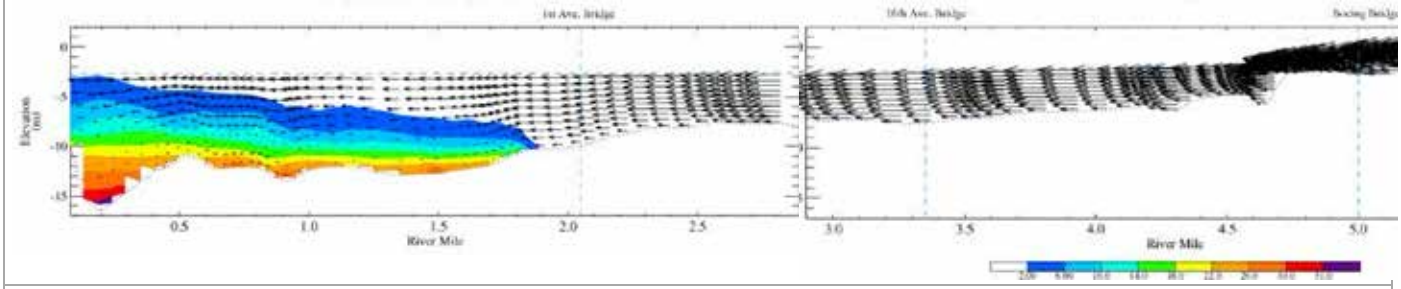


Figure D. 100 year high-flow event, low tide, and minimal extent of salt-water wedge

Figure 2-2. Salt wedge and salinity gradient in a model simulation of a spring tide in the LDW

Estuarine circulation results in a net upstream flow of saline water from the downstream end of the LDW; the further upstream the extent of the salt wedge, the longer its residence time[4] in the LDW. Depending on the extent of tidal forcing and the downstream flow rate, varying levels of turbulence along the saline / freshwater interface can occur, which results in mixing of these two layers and flushing of the brackish water out of the system (Geyer 2004; NOAA 2008). This dynamic affects contaminant concentrations in bottom water, as discussed in Section 2.3.

During each 24-hour period, the LDW experiences approximately two high tides and two low tides (two full tidal cycles are completed every 24 hours and 50 minutes), with tidal elevation changes that can fluctuate by more than 14 ft in a given 24-hour period.[5] Flow rates on the LDW are influenced by tidal cycles, storm events, and the Howard Hanson Dam, which was constructed in 1961 and is located approximately 65 mi upstream of the LDW. The dam was constructed to control water flows for two purposes. First, it provides flood control during the fall and winter, and second, it augments flows during the summer to improve fish habitat (USACE 2017). Since the construction of the dam, flows in the LDW have averaged approximately 1,340 cubic feet per second (cfs) and have rarely exceeded 12,000 cfs. Prior to dam construction, flows ranged from 15,000 to 30,000 cfs during the largest storm events (AECOM 2012). As described in the LDW RI (Windward 2010a) and FS (AECOM 2012), high-flow events and their recurrence intervals are as follows:

- 100-year high-flow event – 12,000 cfs
- 10-year high-flow event – 10,800 cfs
- 2-year high-flow event – 8,400 cfs

These LDW flow rates are the result of the combined influence of water releases from the Howard Hanson Dam and runoff into the Green River and the LDW from precipitation.

During the winter, excess water is held in the dam reservoir and released as soon as possible after a storm event to create space in the reservoir for water from the next storm event. In the spring (when the threat of flooding has passed), water is stored behind the dam until the summer months, when it is released as needed to regulate low flows (USACE 2017). Water is released from the dam on a daily basis, with daily average dam release rates[6] generally ranging from 200 to 600 cfs during the dry summer months (August and September) and from 800 to 1,200 cfs during the wet winter

[4] Residence time is the average time a parcel of water spends in a given body of water before being exchanged (i.e., leaving that body of water).

[5] Tidal elevations are based on the Duwamish Waterway Station at Eighth Avenue South (NOAA Station ID: 9447130).

[6] Dam release rates are as measured at the US Geological Survey (USGS) gage just below the Howard Hanson Dam (Gage 12105900).

months (November to March) (USGS 2016, 2017). After big storm events with heavy precipitation, dam release rates can be much higher, well above 2,000 cfs. A dam release rate greater than 2,000 cfs has been used by King County and USGS water sampling programs to define a significant dam release (King County 2014; USGS 2016, 2017). The effect of these flow dynamics was considered in the proposed study design for surface water, which is described in Section 3.2.4.

2.2.2 Sediment

As shown in Figure 10-1 of the RI, LDW sediment includes a surface layer (i.e., the biologically active zone [BAZ]), recent sediments (i.e., sediments deposited over the past 50 years), and both an upper and lower alluvium layer. As described in the LDW RI (Windward 2010a), the BAZ refers to the upper 10 cm of the sediment where sediments are mixed by the feeding and burrowing behaviors of benthic invertebrates. Understanding the composition and mixing of this layer—which represents the sediment where the majority of benthic invertebrates reside and the primary sediment to which fish and shellfish are exposed—is a critical component of the physical CSM.

Sediment dynamics (including scour, erosion / deposition of sediment, and sediment transport) were characterized as part of the sediment transport model (STM) (QEA 2008; AECOM 2012; Windward 2010a). In addition to accounting for flows and sediment inputs from the Green River upstream of the LDW, the model estimated lateral inputs to the system (e.g., from streams, storm drains, and combined sewer overflows [CSOs]). As described in detail in the LDW FS (AECOM 2012), the STM showed that the LDW is a net depositional environment. Of the approximately 185,000 metric tons of sediment that, on average, enter the LDW from the Green River annually, an average of approximately 100,000 metric tons (54%) annually settle out in the LDW (AECOM 2012).[7] Sedimentation rates are estimated to be approximately 0.5 cm per year in the intertidal areas, 1 to 3 cm per year in most subtidal areas, and up to 30 cm per year in the turning basin from RM 4.6 to RM 4.7 (Map 2-1). The turning basin essentially acts as a trap for much of the incoming sediment from the Green River, which is the source of more than 99% of all sediment (by mass) entering the LDW. The remaining less than 1% of incoming sediment originates from streams, storm drains, CSOs, and other lateral sources. Although the lateral inputs account for only a small fraction of sediment, on average, they have higher contaminant concentrations than those in incoming sediment inputs from the upstream Green River (AECOM 2012).

As described in Section 2.3 of the FS (AECOM 2012), the STM also evaluated bed stability and the potential for scour due to ship traffic and high-flow events.

[7] Annual sediment loads in the LDW are based on the results the STM, as presented in the LDW FS (AECOM 2012), which are based on the 10-year STM simulation results.

- **Scour from passing ships** – Scour from passing ships traveling at typical rates of speed (2 to 3 knots[8]) is not expected to exceed 1 cm in any area of the LDW (AECOM 2012). For ships traveling at the LDW speed limit of 5 knots, average scour is expected to range from 1 to 2 cm in Reach 1, and less than 1 cm in Reaches 2 and 3.
- **Localized ship scour –** In addition to scour from passing ships, localized scour associated with vessels (primarily tugs maneuvering large vessels such as barges or cargo ships) can occur in active berthing areas (AECOM 2012). Scour marks in the LDW range in depth from a few centimeters to more than 30 cm, although most are less than 10 cm in depth (Map 2-2) (AECOM 2012).
- **Scour from high-flow events** – During extreme events, net erosion is expected in some areas of the LDW, with the highest erosion rates occurring upstream of RM 2.8 (Map 2-3). For example, during a high-flow event with a 100-year return interval, the STM predicts that net erosion occurs in 18% of the LDW, generally to a depth of 10 cm below the sediment surface (and to no more than 22 cm below the sediment surface) (AECOM 2012). Most areas subject to these high-flow scour events are net depositional on longer timescales (Map 2-1).

Together, the various actions that contribute the disturbance of bedded sediment (scour and erosion, as well as natural processes such as bioturbation) result in the incoming sediment being mixed with older bedded sediments (AECOM 2012). The depth of this mixing varies as described above, but primarily occurs within the BAZ (i.e., the top 10 cm of the sediment).

2.3 CONTAMINANT CONCENTRATIONS

The physical processes described above are important in understanding the distribution of contaminant concentrations (and how they may change) in sediment and water. These patterns, along with characteristics such as the amount of organic carbon present in LDW sediments and suspended solids,[9] influence how organisms in the LDW (such as benthic invertebrates, shellfish, and fish) are exposed to contaminants, and how contaminants bioaccumulate in tissue directly from sediment, porewater, and surface water, as well as via the food chain.

The patterns in the spatial and vertical distributions of contaminants in sediment result from interactions among a variety of factors, including the proximity and magnitude of contaminant sources (particularly historical sources), as well as the physical processes described in Sections 2.2 (i.e., surface layer dynamics, transport and deposition of sediment within the LDW over time, and localized conditions that affect sediment

[8] Typical rates of speed for ships in the LDW are based on the information reported from personal communications in the LDW FS (AECOM 2012).

[9] The average total organic carbon (TOC) content in LDW sediments is 1.9%, as reported in the LDW RI (Windward 2010a).

mixing such as scour and resuspension). Thus, sources (both historical and recent) and the sediment dynamics described above are important in understanding the current patterns of contaminant concentrations in sediment and how they are predicted to change.

Overall, sediment remedial actions that have been conducted in the LDW, source control efforts, and incoming cleaner sediment from the Green River are resulting in decreasing contaminant concentrations in sediment. These concentrations are predicted to continue to decrease in the years to come as a result of several factors, including sediment remediation, source control actions, and sediment inputs from upstream (AECOM 2012).

Contaminant concentrations in water (both filtered and unfiltered) have greater temporal variability than those in sediment. Causes of this variability can include river conditions related to flow rates based on dam releases and recent precipitation. For example, Green River surface water data analyzed for polychlorinated biphenyls (PCBs) highlight the importance of dam releases, as well as local precipitation events (both the day of and prior to sampling[10]), in affecting PCB concentrations in water (King County 2014; Windward 2010a).

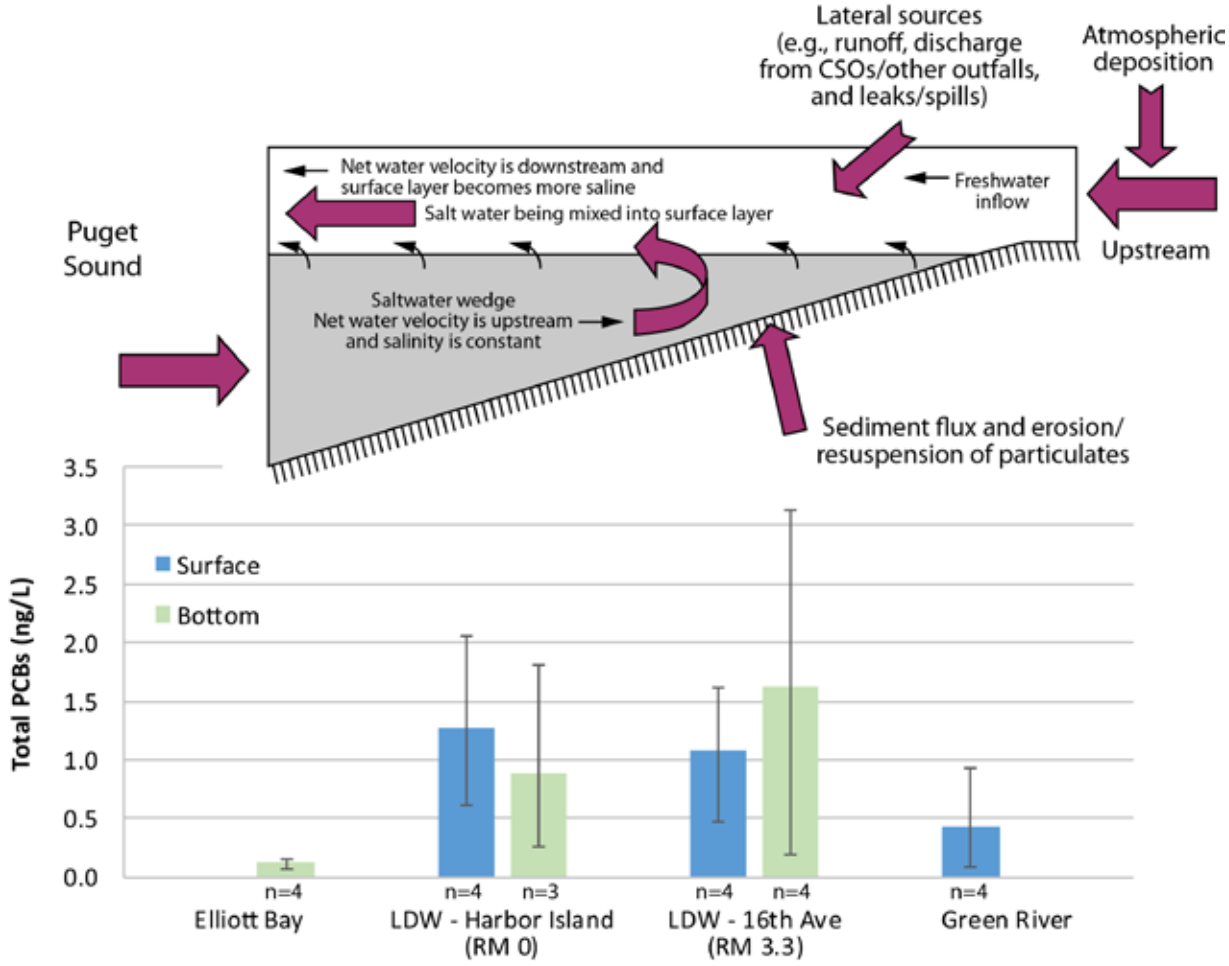
Concentrations of PCBs detected in surface water samples collected from the Green River during periods of rainfall without significant dam releases (i.e., dam release rates less than 2,000 cfs) were higher than concentrations in samples collected during baseflow conditions[11] (both wet and dry) and during times when significant dam releases were occurring. This was particularly true during storm events (defined as more than 0.25 in. of rainfall during a 24-hour period) when significant dam releases were not occurring, a condition that happens most frequently in the early fall (September / October) (King County 2014). Similar patterns were observed by King County for polycyclic aromatic hydrocarbons (PAHs), while other contaminants such as arsenic were not found to have higher concentrations during storm events (King County 2014).

Figure 2-3 presents a conceptual model for PCB transport in the LDW, along with a graphic of total PCB concentrations in LDW surface water samples collected by King County in 2005 (Mickelson and Williston 2006). In this model, PCB concentrations detected in LDW surface waters are affected by flow rates as well as estuarine circulation. Higher PCB concentrations have been detected in the bottom layer of the LDW at RM 3.3 than at RM 0, possibly due to the increased residence time of bottom

[10] The influence of precipitation events prior to sampling is dependent on the duration of the storm event.

[11] Baseflow conditions are defined as average seasonal flow rates. As described in Section 2.2.1, average dam release rates generally range from 200 to 600 cfs during the dry summer months (August and September) and from 800 to 1,200 cfs during the wet winter months (November to March) (USGS 2016, 2017). Dam release rates are as measured at the USGS gage just below the Howard Hanson Dam (Gage 12105900).

water and flux from sediment farther upstream. The PCB concentrations in the surface layer increase from upstream to downstream (Figure 2-3), likely reflecting greater cumulative mixing with the bottom water (Stern 2015). In addition, lateral sources influence surface layer concentration patterns.



Data source: Mickelson and Williston (2006).

Figure 2-3. Simplified conceptual model of PCB transport in LDW surface water

In contrast to the longitudinal (upstream versus downstream) distribution of concentrations within the LDW, the available data suggest minimal differences in lateral distribution (i.e., from shoreline to shoreline) of contaminant concentrations, indicating that the waterway is laterally well mixed. As presented in the LDW RI (Windward 2010b), King County collected water samples from October 1996 to June 1997 for the analysis of metals and semi-volatile organic compounds (SVOCs) from transects across the LDW as part of its water quality assessment (King County 1999).

The metals[12] data suggested that differences in concentrations across the waterway were small, even in transects located near large CSOs.[13]

In addition, as part of sampling conducted by King County in 2011 and 2012 in the Green River (near the Foster Links golf course in Tukwila, Washington), chemical and conventional parameter concentrations in samples collected from the west side of the river (where the majority of samples were collected) were compared with those in composite water samples collected in a transect across the river. Concentrations in these samples were found to be similar between the two sampling methods for all but PCBs, indicating that the Green River is well mixed (King County 2014). Total PCB concentrations in samples collected from the west side of the Green River using the auto-sampler were higher than those in the cross-river composite samples (King County 2014). However, later investigations indicated that this difference was almost entirely due to auto-sampler equipment PCB contamination rather than differences in concentrations in the river (Leidos 2016).[14]

[12] SVOCs were infrequently detected, so this evaluation could not be conducted for these contaminants. Other chemicals (e.g., PCBs) were not analyzed throughout the monitoring period because they were not detected during early sampling events.

[13] Sampling did not specifically target CSO discharge events, although some discharge event data were included in this dataset.

[14] King County is currently conducting a study to isolate the source of the PCBs from the auto-sampler equipment. Data indicate the source to be the type of silicone tubing used (Williston et al. 2016).

3 Tasks

Tasks 2 through 10 are described in this section, including the purpose of each task and its design and rationale. These tasks are defined in accordance with the statement of work in the third AOC amendment (EPA 2016).

3.1 TASK 2: EXISTING DATA COMPILATION

The purpose of Task 2 is to identify, review, compile,[15] and summarize LDW and upstream data collected since the RI/FS (Windward 2010a; AECOM 2012). As described in the third AOC amendment (EPA 2016), Task 2 involves compilation of data collected from 2010 to 2016 and compilation of data collected after 2016,[16] including data collected as part of the pre-design studies. As described in Appendix C of this work plan, these data will be incorporated into the LDW database.

In the first step of Task 2, a *Technical Memorandum: Compilation of Existing Data* (hereafter referred to as the data compilation memorandum) was prepared, as described below, and submitted to EPA (Windward and Integral 2017b). The compiled data (Appendix C of the data compilation memorandum) included the following:

- **LDW data** – Sediment, tissue, surface water, porewater, and seeps
- **Upland data** – Storm drain and combined sewer system source tracing solids data from the LDW drainage basin and groundwater[17] and bank soil data from adjacent upland areas
- **Upstream data** – surface water and suspended solids

The third amendment to the AOC (EPA 2016) stated that only data obtained or made available since April 2010 were to be compiled. However, it was not always possible to determine when the data were obtained or made available; therefore, any data collected in or after 2010 were targeted to collect all relevant data not already in the RI/FS dataset.[18] The temporal and spatial scopes of the data are summarized in Table 3-1.

[15] Data compiled as part of Task 2 will ultimately be incorporated into the LDW database.
[16] Only data that are made available for the duration of the pre-design studies will be compiled.
[17] The groundwater data were submitted as part of a separate compilation (see Section 4).
[18] A search was conducted for pre-2010 data from EAA monitoring events that were not included in the RI/FS; no data were identified.

Table 3-1. Data compilation scope

Medium	Spatial Extent	Date Range[a]	Data Quality Review Required per AOC
In-waterway Data			
Sediment[b]	RM 0 to RM 5 of the LDW	collected in or after 2010[c]	yes
Surface water			
Tissue			
Porewater			
Seep			
Upland Data			
Bank soil	RM 0 to RM 5 along the banks of the LDW	collected in or after 2010	no
Storm drain/combined sewer system solids	drainage basins discharging to the LDW		
Groundwater[d]	wells closest to the LDW	most recent data collected	
Upstream Data			
Suspended solids – chemistry and particle size distribution	Green/Duwamish River at Foster Links (RM 10)	collected in or after 2010	no
Surface water			

[a] Data were included in the draft data compilation memorandum if they were made available prior to December 20, 2016. Additional data will be compiled during the pre-design studies as appropriate.

[b] Surface and subsurface sediment.

[c] No pre-2010 data from EAA monitoring events were identified that were not already in the FS database.

[d] Groundwater data were submitted as part of a separate compilation.

AOC – Administrative Order on Consent
EAA – early action area
FS – feasibility study
LDW – Lower Duwamish Waterway
MHHW – mean higher high water
MLLW – mean lower low water
RM – river mile

Available data were acquired from LDWG, Ecology's Environmental Information Management (EIM) database, and Ecology during the drafting of the data compilation memorandum.

The LDW data (i.e., sediment, tissue, surface water, porewater, and seep data collected from the LDW site) underwent a data quality review to determine if they met data quality objectives (DQOs) consistent with those developed for the RI/FS using Superfund guidance. If so, the data were summarized, compiled in the LDW dataset, and determined acceptable for all uses. If LDW data did not meet DQOs, they were summarized, compiled in the LDW database, and flagged for conditional use. For example, data from the EIM database did not meet DQOs because quality control (QC) backup was not available. Data (including surface and subsurface sediment and porewater data) collected at locations that were subsequently dredged or remediated were excluded from the compilation.

Upstream data (i.e., surface water and suspended solids) and adjacent LDW data (i.e., groundwater, storm drain/combined sewer system solids, and bank soils) collected since January 2010 were also summarized and compiled in the database. Data reviews were not conducted, per the AOC, but an overview of any available data quality information was provided. These data were flagged for conditional use.

All of the Task 2 data acquired to date were presented in Appendix C of the draft data compilation memorandum. This appendix contained tables summarizing the sources and types of data, sampling years, numbers of samples, and data quality reviews (if conducted) (Windward and Integral 2017b). Figures showing data locations (relative to RI/FS data locations), outfall locations, in- and over-water structures, and property lines were included.

The data compilation memorandum (Windward and Integral 2017b) also provided an overview of the following studies:

- EPA Regional Applied Research Effort (RARE), which involved a study of inorganic arsenic bioaccumulation in clam tissue, and the potential relationship with sediment, surface water, and porewater
- Massachusetts Institute of Technology (MIT) study, which is using polyethylene (PE) passive samplers to estimate freely dissolved PCB concentrations in LDW surface water and porewater in an attempt to better understand the relationship among PCB concentrations in surface water, surface sediment, and porewater
- LDWG ENR/AC pilot study, which is assessing the potential effectiveness of AC in combination with the placement of an ENR layer to reduce the bioavailability of PCBs in sediment in the LDW

All of these studies have been designed, in part, to assess the relationships among concentrations in tissue, sediment, or porewater. The data from these studies were not available when the draft data compilation memorandum was prepared; therefore, an overview was provided rather than an analysis of the data. These data were evaluated as part of the porewater addendum (Appendix E).

As described in Appendix C of this work plan, the data from these three studies (in addition to relevant and acceptable data collected over the course of this project) will be incorporated into the LDW database when available.

3.2 TASK 3: QUALITY ASSURANCE PROJECT PLANS

The DQOs, conceptual study designs, and general sampling and analytical methods for baseline sediment, tissue, surface water, and source-related sediment (near-outfall sediment and bank soils) and seep sampling efforts are discussed in this section. A

QAPP will be prepared for each of the sample media,[19] which are described in the following subsections. The QAPPs will each contain a table briefly summarizing the approach in terms of the seven-step DQO process (EPA 2006).

Porewater is discussed in an addendum to this work plan (Appendix E). The addendum presents porewater DQOs and the need for additional data collection based on existing data, data being collected for other studies, and the objectives of the pre-design studies. The conceptual design for the porewater data collection effort is described in the addendum, which references which QAPP will present detailed porewater study designs.

3.2.1 Sediment QAPP

This section outlines the components of the sediment QAPP. The LDW ROD establishes cleanup levels for sediment that include two sediment compliance intervals (EPA 2014):

- Surface sediment from the 0–10-cm interval throughout the LDW for RAOs 1, 2 (netfishing), 3,[20] and 4
- Sediment from the 0–45-cm interval in relevant[21] intertidal areas for RAO 2 (clamming and beach play)

Regarding sediment sample collection, the third amendment to the AOC (EPA 2016) directs the following:

- The collection of 0–10-cm interval sediment samples for site-wide baseline characterization
- The collection of 0–45-cm interval sediment samples in clamming areas and beach play areas for baseline characterization
- The collection of individual 0–10-cm sediment samples to assist in identifying site-wide trends and changes in surface sediment quality over time in MNR areas,[22] and for archival in case additional PCB congener data are needed
- The collection of 0–10-cm sediment samples near outfalls in uncharacterized areas to assist in Ecology's source control efforts
- The collection of bank samples in uncharacterized, erodible areas to assist in Ecology's source control efforts

[19] QAPPs for surface water and fish and crab sampling have been prepared and approved by EPA in parallel with this work plan (see Section 4).

[20] The compliance interval for RAO 3 is 0–10 cm. Compliance with RAO 3 will be assessed as part of design and post-remedy monitoring.

[21] Clamming areas and beach play areas were identified in the RI (Windward 2010a).

[22] It is acknowledged that the remedial boundaries and technology assignments portrayed in ROD Figure 18, titled *Selected remedy*, are likely to change following design. Thus, any reference to MNR areas in this work plan refers to preliminary MNR areas.

Each of these efforts is discussed separately in the following subsections.

3.2.1.1 Baseline surface sediment for site-wide RAOs (0–10 cm)

The DQOs for the establishment of baseline conditions in 0–10-cm LDW surface sediment samples are as follows:

- To establish baseline, site-wide 95% upper confidence limit for the mean (95UCL) concentrations of RAOs 1, 2, and 4 risk drivers[23]
- To establish a baseline, site-wide spatially weighted average concentration (SWAC) to serve as the foundation for assessing trends from before to after sediment remediation for RAO 1, 2, and 4 risk drivers

The baseline surface sediment sample design is tailored to the DQOs above; baseline for RAOs 1, 2, and 4 will be established based on data from a single site-wide sampling event. Sediment sampling can then be repeated over time to generate comparable datasets to assess progress toward cleanup goals, and to assess the effectiveness of the remedy in attaining the site-wide RAOs. Baseline concentrations will reflect the combined effects of 1) cleanup actions at approximately 29 ac of EAAs, 2) ongoing source control, and 3) ongoing natural recovery throughout the LDW. Site-wide SWAC comparisons over time will establish trends in sediment concentrations, while the 95UCL is the ROD compliance metric for surface sediment (EPA 2014).

Study Design and Rationale

The sampling design for baseline surface sediment was developed based on a statistical evaluation to ensure representative coverage of the LDW (Appendix A). To ensure that baseline surface sediment data are evenly distributed throughout the waterway, a set of irregularly shaped grid cells of approximately equally sized areas was established, and a sample location was randomly selected within each grid cell[24] (Map 3-1). Because each sample is representative of an equal area, the arithmetic average will be the same as the SWAC, and the calculation of the 95UCL will be straightforward.

The number of grid cells selected to characterize the site-wide average (as SWAC and 95UCL) was based on simulated variance estimates and EPA direction.

Post-remedy variance was estimated using surface sediment data for PCBs[25] from MNR areas in the LDW as designated in Figure 18 of the ROD (EPA 2014).[26] The simulations

[23] Risk drivers are PCBs, dioxins/furans, carcinogenic polycyclic aromatic hydrocarbons [cPAHs], and arsenic (ROD Table 19, titled *Cleanup levels for PCBs, arsenic, cPAHs, and dioxins/furans in sediment for human health and ecological COCs [RAOs 1, 2, and 4]*). PCBs are the only risk drivers for RAO 4. RAO 3 is discussed in Section 3.2.1.2.

[24] Ten of the samples were not randomly selected; rather, they were placed to reoccupy existing locations (see Section 3.2.1.2).

[25] Sediment data for the other three risk drivers, arsenic, cPAHs, and dioxins/furans, were also reviewed. The PCB data had the highest variability, so they were used in the sampling design to be conservative (see Appendix A).

presented in Section 2 of Appendix A do not include data from any areas slated for active remedies (i.e., dredging, capping, or enhanced natural recovery [ENR]). So while the MNR dataset used for these simulations is expected to approximate or overestimate the variability post-remediation, it is likely to underestimate the population variance that may be seen during the baseline sampling period. The simulations are expected to overestimate the population variance following implementation of the remedy, which will reduce variance in sediment concentrations throughout the LDW since clean sand will be the post-remediation surface in all active remedy areas. A spatially explicit bootstrapping approach was used to simulate variability and the distributional form of the data expected from the proposed sampling design. For each of the bootstrap samples (B = 10,000), goodness-of-fit tests were run to identify whether the results were best described by a normal or gamma distribution, and the variability (i.e., the coefficient of variation [CV]) within each bootstrap sample was calculated. The distribution of the CVs across the 10,000 bootstrap replicates was used to identify the expected and upper bound on the variability from the actual post-remediation environment.

While the data used in these simulations are dated and limited in certain areas, the results from the simulations provide an approximation of the relative variance that may be expected during post-remediation sampling. Using a CV value that exceeded the maximum value observed in the simulations, an approach of 140 samples combined into 20 composite samples was proposed. After reviewing this proposed approach and considering the limitations of the dataset on which it was based, EPA directed that a more conservative assumption about variance be used resulting in an approach with 24 composite samples of 7 samples each (for a total of 168 field samples). This approach, which uses an irregular grid of 168 cells of approximately equal area, is expected to result in a relative margin of error (RME)[27] for the mean of 25% or lower, which is less than analytical variability.[28]

One sample was randomly placed in each of the 168 cells using a geographic information system (GIS) with a spatial requirement that the sample locations must be at least 150 ft[29] from one another to minimize spatial autocorrelation (Appendix A). Once collected, the surface sediment samples from these 168 cells will be combined into 24 composite samples for analysis (Map 3-2), and individual samples will be retained in archive for analysis as needed. Each composite sample will contain seven samples. The

[26] It is acknowledged that the remedial boundaries and technology assignments portrayed in ROD Figure 18, titled *Selected remedy*, are likely to change following design.

[27] RME is measured as the width of the 95UCL as a percent of the mean.

[28] The analytical precision required by EPA functional guidelines for the analytical methods typically used in sediment characterization ranges from 20 to 50%, comparable to a range of 16 to 42% for RME as defined for this project.

[29] This minimum separation distance was reduced from the 200 ft used in Appendix A because the sampling grids are smaller.

analysis of composites is a statistically efficient and cost-effective approach to characterize site-wide concentrations. The composite areas and the remedy technology assignments (as preliminarily mapped in the ROD) are provided in Map 3-3.

In future years of monitoring, the number of samples per composite should remain consistent to maintain year-to-year comparability of the datasets. The numbers of field samples and composite samples may change in response to updated information about site variance, and to achieve a desired RME for the site-wide mean. In this way, a robust site-wide SWAC and 95UCL can be calculated for each sampling event.

Sampling and Analytical Methods

Surface sediment samples will be collected as 0–10-cm grab samples[30] following the RI sediment investigation methods (Windward 2006), which are consistent with surface sediment standardized collection and processing procedures for the Puget Sound area (PSEP 1997). These samples will be composited as described above.

The surface sediment composite samples will be analyzed for the contaminants of concern (COCs) for RAOs 1, 2, and 4 (PCBs, total arsenic, cPAHs, and dioxins/furans) (ROD Table 19) (EPA 2014) and conventional parameters, including TOC, grain size, and total solids. Black carbon will also be analyzed. The analytical methods and associated RLs for each COC are presented in Table 3-2 and compared to the cleanup levels for each of the RAOs. The analytical methods for the conventional parameters are provided in Appendix B.

Table 3-2. RAO 1, 2, and 4 COCs and associated RLs and cleanup levels for baseline site-wide surface sediment (0–10-cm) composite samples

COC	Method	Unit	RL	Cleanup Levels[a]		
				RAO 1	RAO 2	RAO 4
PCBs	EPA 8082A (Aroclors)[b]	µg/kg dw	20	2	1,300	128
	EPA 1668C (congeners)	µg/kg dw	0.0004[c]			
Total arsenic	EPA 6020A	mg/kg dw	0.500	na	7	na
cPAH	EPA 8270D-SIM	µg TEQ/kg dw	4.5[d]	na	380	na
Dioxins/furans	EPA 1613B	ng TEQ/kg dw	1.14[e]	2	37	na

[a] All of these cleanup levels for surface sediment (0–10 cm) are LDW-wide values with a 95UCL compliance measure.

[b] If none of the PCB Aroclors are detected in a sample, then the sample will be submitted for analysis of PCB congeners.

[c] The PCB RL is based on the LMCL from Axys and represents the maximum value for an individual PCB congener. Individual congener LMCLs are listed in Appendix B. The reported LMCL will be adjusted based on the mass of each sample.

[30] Surface sediments will be collected from each location using a double 0.1-m^2 van Veen grab sampler from a sampling vessel, if feasible. Some intertidal locations may be too shallow to access from a sampling vessel, in which case surface sediments will be sampled from the shoreline during low tide.

[d] The RL for the cPAH TEQ value was calculated using one-half the RL for each of the cPAH compounds and the appropriate TEF values (California EPA 2009).

[e] The dioxin/furan RL is based on the laboratory minimum calibration level from Axys; the dioxin/furan mammalian TEQ value was calculated using one-half the RL for each dioxin/furan compound and appropriate mammal TEF values (Van den Berg et al. 2006).

95UCL – 95% upper confidence limit for the mean
Axys – Axys Analytical Services, Ltd.
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
EPA – US Environmental Protection Agency
LDW – Lower Duwamish Waterway
LMCL – lower method calibration limit
na – not applicable
PCB – polychlorinated biphenyl
RAO – remedial action objective
RL – reporting limit
SIM – selective ion monitoring
TEF – toxic equivalency factor
TEQ – toxic equivalent

Based on the comparison with cleanup levels, all of the RLs are sufficient. For PCBs, the PCB Aroclor method (EPA 8082A) RL of 20 µg/kg dry weight (dw) is higher than the RAO 1 cleanup level of 2 µg/kg dw. However, PCBs in baseline sediment samples are likely to be detected at concentrations above 20 µg/kg dw, since they were detected in 94% of the 1,390 sediment samples in the FS dataset using the PCB Aroclor method. If none of the PCB Aroclors are detected in a particular composite sample, then that sample will be analyzed for PCB congeners with a method RL of 0.004 µg/kg dw.[31]

3.2.1.2 Individual 0–10-cm sediment samples

The DQOs for the collection and analysis of individual LDW surface sediment samples (0–10 cm) are as follows:

- To compare (on a point-by-point basis) concentrations in baseline samples collected from within MNR areas to the (benthic) cleanup levels presented in ROD Table 20[32] (EPA 2014)
- To support the evaluation of site-wide trends and comparisons of concentrations to predicted natural recovery in MNR areas[33]

A subset (20) of the surface sediment grab samples that are located in MNR areas (described in Section 3.2.1.1) will be analyzed for RAO 3 COCs.

Characterization relative to RAO 3 and location-specific evaluations of MNR status and progress will be addressed during design and long-term monitoring (see Table 1-1 and

[31] The PCB RL is based on the laboratory minimum calibration level (LMCL) from Axys Analytical Services, Ltd. (Axys) and represents the maximum value for an individual PCB congener. Individual congener LMCLs are listed in Appendix B. The reported LMCL will be adjusted based on the mass of each sample.

[32] ROD Table 20 is titled *Sediment cleanup levels for ecological (benthic invertebrate) COCs for RAO 3*. MNR areas are preliminary because remedial boundaries and technology assignments portrayed in ROD Figure 18, titled *Selected remedy*, are likely to change during remedial design.

[33] Concentrations are not expected to meet natural recovery predictions during baseline sampling because the projections are for 10 years post-remedy.

Appendix D). The data collected as part of the pre-design studies are not being collected to delineate MNR areas or to assess MNR area compliance.

Study Design and Rationale

Of the 168 locations sampled for the composite samples (Map 3-1),[34] a subset of 20 individual locations in MNR areas (based on ROD Figure 18 (EPA 2014)) will be used for this analysis. Ten of these locations[35] will reoccupy LDW RI/FS surface sediment locations in MNR areas with sediment cleanup objective (SCO) exceedances based on existing data; these locations will constitute fixed station locations that will be resampled during future monitoring events. The other 10 locations will be selected randomly in MNR areas to characterize the range of conditions in the MNR areas. These 20 samples will be analyzed for the target analytes in Table 3-3, with archives retained for potential congener analyses as described in the next subsection. The samples from these 20 locations will constitute a split-panel sampling design for measuring statuses and trends in the MNR areas.

Table 3-3. RAO 3 COCs and associated RLs and cleanup levels for individual 0–10-cm sediment samples

COC	Method	RL	Cleanup Levels for RAO 3[a]
Metals (mg/kg dw**)**			
Arsenic	EPA 6020A	0.500	57
Cadmium	EPA 6020A	0.100	5.1
Chromium	EPA 6020A	0.500	260
Copper	EPA 6020A	0.500	390
Lead	EPA 6020A	0.100	450
Silver	EPA 6020A	0.200	6.1
Zinc	EPA 6020A	4.00	410
Mercury	EPA 7471B	0.025	0.41
PAHs and SVOCs (µg/kg dw**)**			
Benzo(a)anthracene	EPA 8270D	20.0	2,200[b]
Benzo(a)pyrene	EPA 8270D	20.0	1,980[b]
Total benzofluoranthenes	EPA 8270D	40.0	4,600[b]
Chrysene	EPA 8270D	20.0	2,200[b]
Dibenzo(a,h)anthracene	EPA 8270D	20.0	240[b]
Indeno(1,2,3-cd)pyrene	EPA 8270D	20.0	680[b]
Anthracene	EPA 8270D	20.0	4,400[b]
Acenaphthene	EPA 8270D	20.0	320[b]
Benzo(g,h,i)perylene	EPA 8270D	20.0	620[b]

[34] Actual baseline locations will be selected in the sediment QAPP.

[35] Because these samples also will contribute to the composite design to address DQOs for RAOs 1, 2, and 4 (see Section 3.2.1.1), the number of fixed locations was restricted to limit bias in the site-wide mean estimate.

COC	Method	RL	Cleanup Levels for RAO 3[a]
Fluoranthene	EPA 8270D	20.0	3,200[b]
Fluorene	EPA 8270D	20.0	460[b]
Naphthalene	EPA 8270D	20.0	1,980[b]
Phenanthrene	EPA 8270D	20.0	2,000[b]
Pyrene	EPA 8270D	20.0	20,000[b]
Total HPAHs	EPA 8270D	40.0	19,200[b]
Total LPAHs	EPA 8270D	20.0	7,400[b]
2,4-dimethylphenol	EPA 8270D-SIM	25	29
2-methylnaphthalene	EPA 8270D	20.0	760[b]
4-methylphenol	EPA 8270D	20.0	670
Benzoic acid	EPA 8270D-SIM	100	650
Benzyl alcohol	EPA 8270D-SIM	5	57
Bis(2-ethylhexyl)phthalate	EPA 8270D	50.0	940[b]
Butyl benzyl phthalate	EPA 8270D	20.0	98[b]
Dibenzofuran	EPA 8270D	20.0	300[b]
Dimethyl phthalate	EPA 8270D	20.0	1,060[b]
Hexachlorobenzene	EPA 8270D-SIM	5.0	7.6[b]
n-Nitrosodiphenylamine	EPA 8270D-SIM	5	220[b]
PCP	EPA 8270D-SIM	20	360
Phenol	EPA 8270D	20.0	420
1,2,4-trichlorobenzene	EPA 8270D-SIM	5.00	16.2[b]
1,2-dichlorobenzene	EPA 8270D-SIM	5.00	46.0[b]
1,4-dichlorobenzene	EPA 8270D -SIM	5.00	62.0[b]
PCBs (µg/kg dw**)**			
PCBs	EPA 8082A (Aroclors)[c]	20.0	240[b,c,d]

[a] Per the ROD (EPA 2014), cleanup levels for RAO 3 are based on the benthic SCO chemical criteria in the SMS (WAC 173-204-562). The compliance depth is the 0–10-cm interval.

[b] Organic carbon-normalized criteria were converted to non-normalized values using 2% TOC. Cleanup levels are assessed on organic carbon normalized basis. These values are presented as dry weight values for purposes of comparing to RLs only.

[c] If none of the PCB Aroclors are detected, then the sample will be submitted for analysis of PCB congeners by Method 1668C with an estimated RL of 0.0004 µg/kg dw. The PCB RL is based on the LMCL from Axys and represents the maximum value for an individual PCB congener. Individual congener LMCLs are listed in Appendix B. The reported LMCL will be adjusted based on the mass of each sample.

[d] All discrete 0–10-cm samples analyzed for PCB Aroclors will be archived for potential PCB congener analysis, as discussed in Section 3.2.1.3.

Axys – Axys Analytical Services, Ltd.
COC – contaminant of concern
dw – dry weight
EPA – US Environmental Protection Agency
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LMCL – lower method calibration limit
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
PCP – pentachlorophenol
RAL – remedial action level
RAO – remedial action objective
RL – reporting limit
ROD – Record of Decision
SCO – sediment cleanup objective
SIM – selective ion monitoring
SMS – Washington State Sediment Management Standards
SQS – sediment quality standards
SVOC – semivolatile organic compound
TOC – total organic carbon
WAC – Washington Administrative Code

Sampling and Analytical Methods

Sediment grab samples will be collected using the methods described in Section 3.2.1.1. For locations identified for the analysis of individual samples, the collected sediment will be split; a portion will be collected for an analysis of the individual samples, and a portion will be combined into the composite sample for site-wide RAOs.

The analytical methods proposed for each of the COCs in ROD Table 20 (EPA 2014) are provided in Table 3-3. The method RLs for each COC are compared to the cleanup levels for RAO 3. The cleanup levels for many organic contaminants are organic carbon-normalized values. For the purposes of this comparison, the cleanup levels were converted to dry weight concentrations assuming 2% TOC. Based on this comparison, all of the methods are expected to be sufficiently sensitive for the results to be compared to the cleanup levels. Black carbon will also be analyzed in each of the samples.

3.2.1.3 Evaluation of relationship between total PCBs as sum of Aroclors and total PCBs as sum of congeners

The DQO for the PCB Aroclor versus congener sum evaluation is as follows:

- To assess the relationship between total PCBs based on the sum of detected congeners versus the sum of detected Aroclors in LDW sediment

To assess this DQO, the existing RI/FS and post-2010 (Task 2) data will be reviewed in the sediment QAPP to identify sediment samples analyzed for both PCB Aroclors and PCB congeners. These data will be evaluated to determine if total PCBs calculated using an Aroclor sum and a PCB congener sum appear to be reliably correlated throughout the concentration range sampled. Particular focus will be on the lower concentration range, because the post-remedial PCB concentrations will be lower than the current PCB concentrations.

The relationship based on existing data will be evaluated to ensure that there are sufficient data distributed throughout the concentration range, and to determine whether there are potential outliers at the extremes of the concentration range. If additional data are determined to be necessary, then the total PCB concentrations calculated as the sum of Aroclors in the individual sediment samples analyzed for RAO 3 COCs will be evaluated to determine if any of the samples are suitable for PCB congener analysis. [36] This determination will support the development of a relationship between PCB congener and Aroclor sums.

3.2.1.4 Intertidal baseline sediment for direct contact RAO 2 - clamming and beach play (0–45-cm)

The DQOs for the collection and analysis of surface sediment samples (0–45 cm) for RAO 2 are as follows:

[36] These samples will be archived for potential PCB congener analysis.

- To establish baseline 95UCL concentrations of human health risk drivers for RAO 2 across all potential clamming areas identified in the ROD
- To establish baseline site-wide clamming area mean concentrations to assess trends following sediment remediation for RAO 2 (direct contact – clamming) risk drivers
- To establish baseline 95UCL concentrations for risk drivers to achieve RAO 2 in each of the eight beach areas
- To establish baseline beach area-specific mean concentrations to assess trends following sediment remediation for RAO 2 (direct contact – beach play) risk drivers

Clamming Areas

Potential clamming areas identified in the RI (Windward 2010a) will be sampled to assess baseline conditions in these intertidal areas throughout the LDW. Seventy-one locations will be sampled (Map 3-4), and three separate samples will be collected from each of these locations (in close proximity to each other) for a total of 213 samples. One of the three samples from each location will be included in one of three site-wide composite samples, each representing LDW-wide potential clamming areas.

The total number of locations (71) was determined based on the requirements that every potential clamming area be sampled, and that the number of sampling locations within each area be approximately proportional to the size of the area. In practice, one sampling location is placed in each of the smallest clamming areas, and a proportionally larger number of sampling locations is placed in the larger potential clamming areas. When a clamming area has more than one sampling location, those locations are spatially balanced within the clamming area to avoid clustering. This approach results in a total of 71 sampling locations in clamming areas throughout the LDW (Map 3-4). As an example, the smallest intertidal area is 1.5 ac and has one sampling location, and the largest intertidal area (surrounding Kellogg Island) is approximately 29.7 ac and has 19 sample locations. As will be further discussed in the sediment QAPP, the number of samples in each sampling area is proportional to its physical area, with an average of one sample per 1.3 ac in each of the intertidal areas (Map 3-4).

The concentrations in the three composite samples will be used to estimate the potential clamming area-wide mean, and the variance among the composite samples will be used to calculate the site-wide clamming area 95UCL. A discussion of the 95UCL calculation is provided in Appendix A (Section 3.2). In future monitoring, the locations of the 71 samples in the intertidal clamming areas will be re-randomized to allow unbiased inference about potential clamming area-wide conditions at each point in time.

Sampling and Analytical Methods

At each location shown on Map 3-4, three sediment samples will be collected for a total of 213 sediment samples. Each sediment sample will be collected from the perimeter of

a hole dug to 45 cm deep. The sample will be collected using a stainless steel spoon, and a concerted effort will be made to sample an equal volume throughout the 45-cm depth. The samples will then be combined to create three site-wide composite samples, each of which will each contain 71 samples. The details of the compositing protocols will be provided in the surface sediment QAPP.

Each of the 0–45-cm composite samples will be analyzed for human health direct contact COCs (PCBs, total arsenic, cPAHs, and dioxins/furans) identified in ROD Table 19 (EPA 2014) (Table 3-4). In addition to these COCs, ROD Table 14[37] identified toxaphene as a direct contact contaminant of potential concern (COPC). Toxaphene was not identified as a COC because of its low percent contribution to cumulative excess cancer risk (6% or less) and low detection frequency in surface sediment samples (1%). Available analytical methods for toxaphene have not been sufficiently sensitive to assess this compound in sediment. The methods will be reviewed in the sediment QAPP in order to determine whether to analyze this contaminant.

Table 3-4. RLs and cleanup levels for sediments analyzed for direct contact COCs

COC	Method	Unit	RL	Cleanup Levels for RAO 2[a]	
				LDW-wide Clamming Areas	Individual Beaches
PCBs	EPA 8082A (Aroclors)[b]	µg/kg dw	20	500	1,700
Total arsenic	EPA 6020A	mg/kg dw	0.500	7	7
cPAH	EPA 8270D-SIM	µg TEQ/kg dw	4.5[c]	150	90
Dioxins/furans	EPA 1613B	ng TEQ/kg dw	1.14[d]	13	28
Toxaphene[e]	EPA 8081A	µg/kg dw	25	na	na

Source: Adapted from ROD Table 19 (EPA 2014).

[a] The compliance depth is 0–45 cm, and the 95UCL is the compliance measure on each spatial scale.

[b] If none of the PCB Aroclors are detected in a sample, then the sample will be submitted for analysis of PCB congeners by Method 1668C with an estimated RL of 0.0004 µg/kg dw.

[c] The RL cPAH TEQ value was calculated using one-half the RL for each of the cPAH compounds and the appropriate TEF values (California EPA 2009).

[d] The dioxin/furan RL is based on the laboratory minimum calibration level from Axys; the dioxin/furan mammalian TEQ value was calculated using one-half the RL for each dioxin/furan compound and appropriate mammal TEF values (Van den Berg et al. 2006).

[e] ROD Table 14 identified toxaphene as a direct contact COPC.

95UCL – 95% upper confidence limit for the mean
Axys – Axys Analytical Services, Ltd.
dw – dry weight
COC – contaminant of concern
COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EPA – US Environmental Protection Agency
LDW – Lower Duwamish Waterway
na – not applicable
PCB – polychlorinated biphenyl
RAO – remedial action objective
RL – reporting limit
ROD – Record of Decision
SIM – selective ion monitoring
TEF – toxic equivalency factor
TEQ – toxic equivalent

[37] ROD Table 14 is titled *Summary of COPCs and rationale for selection as COCs for human health exposure scenarios*.

Beach Play Areas

To assess baseline conditions at the eight beach areas identified in the RI (Windward 2010a) (Map 3-5), three composite samples will be analyzed from each beach area. The variance among the composite samples will be used to calculate a 95UCL for each beach area (see Section 3.1 in Appendix A for more information). Similar to the potential clamming area sampling approach, at each of the beach play sampling locations, three separate samples will be collected within several feet of one another. In this way, sediment from each location will contribute to each of the three composite samples per beach area, and the three composites will represent field replicates of the beach-wide mean, capturing small-scale spatial variability as well as sampling and analytical error.

A total of 43 locations[38] will be sampled within the beach areas (Map 3-5). The total number of locations within each beach area is roughly proportional to the size of the beach area. Beach areas of less than 3 ac are assigned three sampling locations (nine samples total), while larger beach areas are assigned more sampling locations. The number of locations contributing sediment to each beach area composite ranges from three to nine per beach, with the locations spatially balanced within each beach.

In future monitoring, the locations of the samples in the intertidal beach areas will be re-randomized to allow unbiased estimates of beach-specific conditions at each point in time. In addition, each individual sample from future monitoring events will be archived for 1 year to enable further investigation on a smaller spatial scale in the event that the post-remediation beach area results are higher than anticipated and exceed cleanup levels.

Sampling and Analytical Methods

The three composite samples per beach will be collected using the same sampling methods described for the clamming scenario, and they will be analyzed for the same analytes (Table 3-4). All of these samples will be from the 0–45-cm interval, to the extent possible.[39]

There are areas that are common to the beach play areas and the potential clamming areas. Therefore, 25 of the potential clamming area locations will also contribute to beach composite samples (Map 3-5). At these locations, sediment samples will be split; a portion of the sample will be composited in the potential clamming area composites and a portion of the sample will be composited in the beach play area composites. An additional 18 locations will be sampled for the beach play area composites to ensure that there are sufficient samples in the beach area composites.

[38] The 43 locations include 25 locations that are also potential clamming area locations and 18 locations that will only be sampled for the beach area composite samples.

[39] Rock, cobble, and other obstructions can prevent sampling to a depth of 45 cm.

3.2.1.5 Source-related sediment samples

In addition to the baseline sediment samples discussed in Sections 3.2.1.1 through 3.2.1.3, targeted source-related sediment sampling will be conducted under the third AOC amendment. These samples are intended to "help Ecology assess the sufficiency of contaminant source control through additional near-outfall sediment sampling and bank sampling" (EPA 2016).

Near-outfall Sediment Sampling

In 2014, Leidos conducted an assessment to identify sediment data gaps near outfalls, evaluate the feasibility of filling those gaps, and provide information needed to conduct additional outfall sediment sampling (Leidos 2014). Based on this assessment, Leidos recommended sediment sampling near outfalls that met the following criteria: 1) the outfall was active or presumed active, 2) it was not adjacent to a cleanup site, and 3) existing surface sediment data (i.e., two sediment samples collected within 50 to 100 ft from 2000 to present) were not sufficient. These outfalls are circled on Maps 3-6a through 3-6c.

To assist Ecology in its source evaluations, the outfalls recommended by Leidos (2014) for additional sediment sampling will be evaluated in the sediment QAPP based on the considerations presented in Figure 3-1. Based on this evaluation, additional source-related surface sediment samples will be collected if the criteria outlined in Figure 3-1 are met. The sediment QAPP will clearly present the results of the evaluation. Considerations regarding the need for additional sediment sampling include:

- Whether sufficient sediment data from the vicinity of the outfall exist[40]
- Whether the outfall can be sampled based on information presented in the Leidos (2014) assessment and consultation with Ecology, EPA, or Leidos

If appropriate based on consultation with the proper entity, a field reconnaissance will be conducted with Ecology to assess the sampleability of the sediments near the outfall prior to finalizing the QAPP. Visual information regarding riprap or other obstructions, such as piers, docks, and pilings, will be documented in the field notes and data report.

[40] Leidos evaluated data collected between 2000 and 2014. The QAPP evaluation will consider all available data in evaluating whether data exist within approximately 50 ft of Leidos-recommended outfalls with diameters of 24 in. or less, or within approximately 100 ft of outfalls with diameters of 24 in. or more.

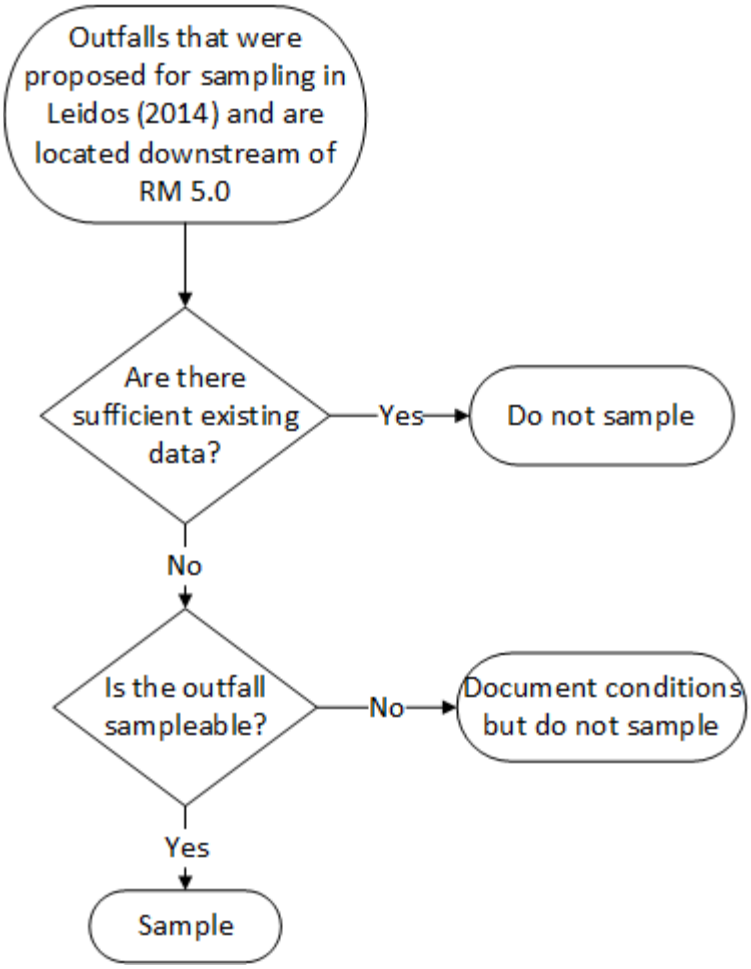


Figure 3-1.Selection criteria for sampling sediment near active outfalls

Sampling and Analysis Methods

If an outfall meets the above criteria for nearby sediment sampling, surface sediment sampling (0–10 cm) will be conducted following the methods discussed in Section 3.2.1.1. As part of the QAPP development, EPA and Ecology will be consulted regarding whether samples will be composited. Samples will be analyzed for the analytes listed in Table 3-3 (ROD Table 20 (EPA 2014)). Samples will also be analyzed for dioxins / furans, if the dioxin / furan toxic equivalent (TEQ) is greater than the remedial action level (RAL) in nearby sediment samples (i.e., samples collected near outfalls will be archived for potential dioxin / furan analysis pending the analysis of the sediment samples described in Sections 3.2.1.1 and 3.2.1.2). Additional details will be provided in the sediment QAPP.

Bank Soil Sampling

Uncharacterized exposed bank areas between +4 and +12 ft mean lower low water (MLLW)[41] may also be sampled to assist Ecology in source control.

In 2011, Hart Crowser sampled bank soils at nine areas on the LDW (Hart Crowser 2012). Eight of the nine areas were selected for sampling by Ecology to "assess the potential of sediment recontamination … because information about past use at the site or adjacent upland areas, or visual observations indicated that there may be suspect material on the bank that could be a source of sediment recontamination." One of the nine areas, the South Park Street end, which is easily accessible by the public, was sampled to confirm that bank soils at that location did not pose a risk to human health. These sampling data were imported to EIM.

In 2016, Leidos produced maps for Ecology delineating which exposed bank areas on the LDW have been characterized and which have not (LDWG 2016) (Map 3-7). This delineation was based on areas identified as exposed bank in the LDW FS (AECOM 2012) and the 2011 bank sampling locations.

To assist Ecology, uncharacterized exposed bank areas will be sampled as part of the pre-design studies if a bank meets the following criteria (Figure 3-2): 1) it is not adjacent to an upland cleanup site under or expected to be under an Agreed Order or an early action; 2) insufficient bank data exist; and 3) the bank can be sampled. The location of the bank area relative to preliminary dredge/cap areas (as identified in ROD Figure 18 (EPA 2014)) will also be considered, in consultation with EPA and Ecology, to determine if bank sampling in these areas may be more appropriately conducted during design.

Bank areas next to cleanup sites under or expected to be under an Agreed Order will not be sampled, because sampling should be done as part of the upland investigation, if needed. The remaining uncharacterized bank areas will be assessed[42] in a field reconnaissance survey to determine whether the locations can be sampled, based on substrate conditions, the presence and condition of overwater structures (which can create unsafe sampling conditions), and the presence of armoring. The method and criteria that will be used to assess whether a bank can be sampled will be provided in the sediment QAPP.

[41] This elevation is approximately equal to mean higher high water (MHHW). NOAA reports MHHW at the Seattle station (Elliott Bay) as +11.36 ft MLLW (NOAA 2013).

[42] Access agreements will be needed in order to perform sampling on private property.

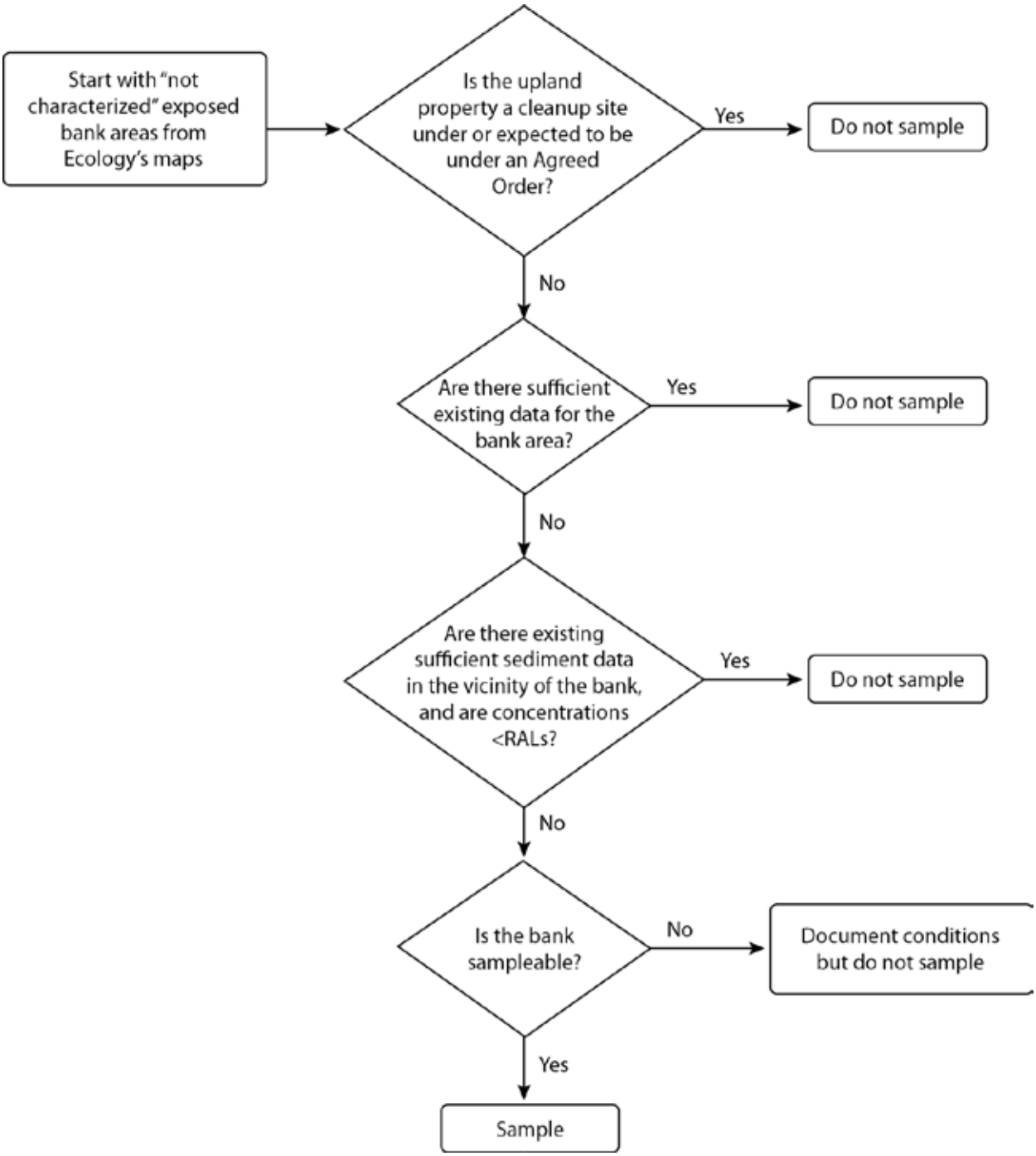


Figure 3-2.Selection criteria for sampling banks

Sampling and Analytical Methods

The reconnaissance survey methods will be identified in the sediment QAPP. The bank areas to be sampled and the number of samples to be collected at each location will be specified based on the survey and the other criteria outlined in Figure 3-2. Samples will be analyzed for the COCs listed in ROD Table 20 (EPA 2014) using the methods in Table 3-4 of this document. Samples will also be analyzed for dioxins/furans, if the

dioxin/furan TEQ is greater than the RAL in nearby sediment samples (i.e., bank samples collected will be archived for potential dioxin/furan analysis pending the analysis of the sediment samples described in Sections 3.2.1.1 and 3.2.1.2). Bank samples will be collected by hand according to the methods outlined in Hart Crowser (2011). Additional details will be provided in the sediment QAPP.

3.2.2 Fish and crab tissue QAPP

The DQOs for the collection and analysis of LDW fish and crab tissue samples are as follows:

- To establish baseline site-wide 95UCL concentrations of risk drivers for comparison to target tissue levels (TTLs) for RAO 1
- To establish baseline site-wide mean concentrations to assess trends following sediment remediation for contaminants with TTLs[43]other

The fish and crab tissue sampling will also support risk communication related to human health consumption of resident seafood (RAO 1).

3.2.2.1 Study design and rationale

Based on the species sampled as part of the RI (Windward 2010a), the results of the fishers study (Windward 2016), and species with TTLs (ROD Table 21), three target species (English sole, shiner surfperch, and Dungeness crab) will be sampled from the LDW to establish baseline conditions.

English sole and Dungeness crab composite samples will be collected from two reaches of the LDW: Reach 1 (RM 0.0 to RM 2.9) and Reach 2 (RM 2.9 to RM 5.0) (Map 3-8). Reach 1 includes all areas where surveyed fishers reported fishing for resident species (Windward 2016). Reach 2 includes areas where surveyed fishers reported fishing for salmon only (Map 3-8). Individual fish and crab collected from within each reach will be composited, and the data across reaches will be combined to calculate 95UCL concentrations across the LDW for comparison to TTLs.

Shiner surfperch composite samples will be collected from four subreaches of the LDW,[44] each comprising one-fourth of the LDW: Reach 1a (RM 0.0 to RM 1.25), Reach 1b (RM 1.25 to RM 2.5), Reach 2a (RM 2.5 to RM 3.75), and Reach 2b (RM 3.75 to RM 5.0) (Map 3-9). Tissue data collected as part of the RI (Windward 2010a) indicated that PCB concentrations and congener patterns showed more spatial differentiation for

[43] As specified in ROD Table 21, titled *LDW resident fish and shellfish target tissue concentrations*, LDW resident fish and crab target tissue concentrations (EPA 2014).

[44] Each of these reaches includes one of the four areas sampled as part of the RI (Areas T1, T2, T3, and T4) (Windward 2010a). Reach 1a contains Area T1, Reach 1b contains Area T2, Reach 2a contains Area T3, and Reach 2b contains Area T4.

shiner surfperch than for other fish and crab species analyzed in the RI.[45] It is noted, however, that many factors influence contaminant concentrations in tissues, not just sediment exposures.

The optimal number of composite samples needed for each tissue type to achieve a RME of 25%[46] will be based on estimates of variability expected in the baseline composite tissue dataset using the RI tissue dataset (Appendix A). For each target species, the 95UCL for the site-wide mean will be estimated from multiple composite samples from each subreach or reach. Individuals will be collected within the targeted subreaches or reaches of the LDW, as described above, and multiple composite samples will be constructed for a given subreach or reach. Composite samples will be used to estimate the mean and variance of composite tissue concentrations within that subreach or reach, and results will be combined to estimate the site-wide mean and its 95UCL using stratified estimates. The stratified design will account for possible differences of mean and variability in composite tissue concentrations across subreaches and reaches.

Based on the analysis presented in Appendix A, a total of 12 samples will be created for English sole (whole body minus fillet; referred to as remainder[47]), English sole (fillet), Dungeness crab (edible meat), and Dungeness crab (whole body), with 6 samples collected in each of the 2 reaches shown in Map 3-8.

To reduce the variability observed in tissue composite samples during the RI sampling, each remainder and fillet English sole composite sample will include 10 fish. If sufficient English sole cannot be caught within a reach, starry flounder will serve as an alternate benthic fish. The authorization process to be followed for alternative species will be discussed in the tissue QAPP, along with compositing considerations.

Dungeness crab (edible meat) composite samples will include edible meat from five individuals, as was done in the RI. Hepatopancreas tissue samples (with equal contributions from 10 crabs each) will also be analyzed.[48] To calculate the

[45] As stated in Windward (2010a), means of wet weight PCB concentrations in shiner surfperch were higher in Areas T2 and T3 and lower in Areas T1 and T4 in 2004, 2005, and 2007, and averaged over all years. Significant relationships between tissue and surface sediment were also identified on a subarea basis for shiner surfperch using 2004 data; PCB concentrations in surface sediment explained more than 50% of the variance in concentrations in tissue. Using 2005 data for shiner surfperch, the relationship was significant but less strong, explaining 29% of the variance. For English sole and Dungeness crab, regression relationships were not significant on an area basis using either 2004 or 2005 data, and PCB homolog patterns were consistent across the entire LDW.

[46] The analytical precision required by EPA functional guidelines for the analytical methods typically used in tissue characterization ranges from 20 to 50%.

[47] The English sole remainder and fillet data will be used to calculate whole-body concentrations.

[48] In each reach, 30 crabs (6 composite samples with 5 crabs each) will be collected to produce 6 edible meat composites and 3 hepatopancreas composites. Each hepatopancreas composite will contain hepatopancreas tissue from the 10 crabs represented in the corresponding 2 edible meat composites. Equal contributions from 10 crabs will be needed for each of the hepatopancreas samples to obtain sufficient mass for analysis.

concentrations in whole-body Dungeness crab for comparison to the TTLs (ROD Table 21 (EPA 2014)), the edible meat concentrations and the hepatopancreas concentrations will be mathematically combined based on the fraction of the whole body represented by each tissue type. Additional (i.e., more than five) individual crabs are not being added to each crab composite sample because it is difficult to collect sufficient numbers of crabs in the LDW.[49] If sufficient Dungeness crabs cannot be caught within a specific reach, slender crab will be considered as an alternate species, similar to the proposal above for English sole.

Based on the analysis presented in Appendix A of the 2007 shiner surfperch data, 3 composite samples per subreach (i.e., Reaches 1a, 1b, 2a, and 2b) for a total of 12 composite samples site wide are needed to achieve an RME of 25%. To reduce variability, each shiner surfperch composite sample will include 15 fish.

Long-term trends in tissue data may be evaluated using long-term monitoring data and parametric or non-parametric regression methods. In the short term, changes in tissue concentrations may be evaluated using a comparison of means between two time periods (e.g., a one-tailed, two-sample comparison, similar to a simple t-test but modified to be appropriate for the stratified sampling design and the distribution of the data). Power analyses,[50] described in Appendix A, indicate that the proposed sample design is expected to detect tissue concentration decreases equivalent to 30 to 75%[51] of the baseline means.

3.2.2.2 Sampling and analytical methods

Fish and crab will be collected using the trawling methods used in the RI (Windward 2010a). In addition, crab traps will be deployed as another method to collect Dungeness crabs. A trawling and collection plan addressing coverage of the subreaches or reaches outlined above is established in the tissue QAPP (Windward 2017a).

All Dungeness crab composite samples will be analyzed for human health seafood consumption COCs identified in ROD Table 14 (PCBs, inorganic arsenic, cPAHs, and dioxins/furans), using the methods listed in Table 3-5. PCB congeners will be analyzed

[49] Dungeness crab catch per unit effort (CPUE) was low throughout the LDW in RI sampling events in 2004, 2005, and 2007. The target size range for Dungeness crabs is ≥ 9 cm total length, which is consistent with the target size range used in the LDW RI (Windward 2010a). Collecting crabs in this size range will maximize the likelihood of collecting sufficient numbers of crabs for chemical analyses; it will also consider the need to collect crabs large enough to be consumed by humans. Additionally, crabs in this size range are mostly adults that may have been exposed to LDW sediments for a longer period of time than juvenile crabs. Only male crabs will be retained.

[50] The power analyses presented in Appendix A calculate the minimum detectable difference (MDD) as the percent decrease from the baseline mean that is expected to be detected with 90% power and 95% confidence.

[51] The design is expected to detect decreases equivalent to the following percentages of baseline means: 40% (English sole fillet), 50% (English sole whole body), 35% (shiner surfperch), 30% (crab edible meat), and 30 to 75% (crab whole body, with and without outlier, respectively).

in a subset of the composites. The number of composites to be analyzed for each tissue type is listed in Table 3-5.[52] To serve as a baseline for long-term monitoring, a subset of samples (as noted in Table 3-5) will also be analyzed for the chemicals listed in ROD Table 14 and the appropriate chemicals listed in ROD Table 18.[53] In combination, these chemicals include selected SVOCs (bis[2-ethylhexyl] phthalate [BEHP], pentachlorophenol [PCP], carbazole, and hexachlorobenzene), tributyltin (TBT), vanadium, and organo-chlorine pesticides. A smaller subset of samples can be analyzed for these chemicals because they are not risk drivers.

Table 3-5. Summary of fish and crab tissue analytes, methods, RL goals, and numbers of tissue composite samples for each analyte

Analyte	Method	RL Goal	TTL (ROD Table 21)	No. of Composite Samples of Each Tissue Type		
				English Sole	Crab[a]	Shiner Surfperch
Total PCBs (µg/kg ww)	EPA 8082A (Aroclors)	4[b]	12 (benthic fish, fillet) 1.8 (pelagic fish, whole body) 1.1 (crab, edible meat) 9.1 (crab, whole body)	12[c] (6 per reach)	12[d] (6 per reach)	12[e] (3 per subreach[f])
PCB congeners (sum) (µg/kg ww)	EPA 1668C	0.0004	12 (benthic fish, fillet) 1.8 (pelagic fish, whole body) 1.1 (crab, edible meat) 9.1 (crab, whole body)	6[g] (3 per reach)	8[g] (4 per reach)	8[g] (2 per subreach)
Inorganic arsenic (mg/kg ww)	EPA 1632	0.010	na	12 (6 per reach)	12 (6 per reach)	12 (3 per subreach)
cPAH (µg TEQ/kg ww)	EPA 8270D-SIM	4.5[h]	na	na	12 (6 per reach)	na
Dioxins/furans (ng TEQ/kg ww)	EPA 1613B	1.14[i]	0.35 (benthic fish, whole body) 0.53 (crab, edible meat) 2.0 (crab, whole body)	12 (6 per reach)	12 (6 per reach)	12 (3 per subreach)

[52] In addition to the subsets of tissue samples to be analyzed for PCB congeners, if none of the PCB Aroclors are detected in a sample, then the sample will be submitted for analysis of PCB congeners. The combination of these methods will ensure that the PCB concentrations are sufficiently sensitive relative to the PCB TTL.

[53] COPCs listed in ROD Table 18, titled *Rationale for selection of contaminants as COCs for ecological risk,* for spotted sandpiper will not be analyzed in fish and crab because only benthic invertebrate tissue and sediment analyses are relevant. Also, the benthic invertebrate COPCs listed in ROD Table 18 will not be analyzed in fish and crab tissue because these COPCs are only applicable in sediment analyses (EPA 2014); likewise cadmium, which was assessed using a dietary approach, will not be analyzed in fish tissue.

Analyte	Method	RL Goal	TTL (ROD Table 21)	No. of Composite Samples of Each Tissue Type		
				English Sole	Crab[a]	Shiner Surfperch
BEHP (µg/kg ww)	EPA 8270D	50.0	na	2 (1 per reach)	2 (1 per reach)	2 (1 per reach[f])
PCP (µg/kg ww)	EPA 8270D	100	na			
TBT (µg/kg ww)	EPA 8270D-SIM	3.86	na			
Vanadium (mg/kg ww)	EPA 6020A	0.004	na			
Aldrin (µg/kg ww)	EPA 8270D/ 1699 Mod	1.0	na			
alpha-BHC (µg/kg ww)	EPA 8270D/ 1699 Mod	1.0	na			
beta-BHC (µg/kg ww)	EPA 8270D/ 1699 Mod	1.0	na			
Carbazole (µg/kg ww)	EPA 8270D	20.0	na			
Total chlordane (µg/kg ww)	EPA 8270D/ 1699 Mod	2.0	na			
Total DDTs (µg/kg ww)	EPA 8270D/ 1699 Mod	2.5	na			
Dieldrin (µg/kg ww)	EPA 8270D/ 1699 Mod	1.0	na			
gamma-BHC (µg/kg ww)	EPA 8270D/ 1699 Mod	1.0	na			
Heptachlor (µg/kg ww)	EPA 8270D/ 1699 Mod	1.0	na			
Heptachlor epoxide (µg/kg ww)	EPA 8270D/ 1699 Mod	1.0	na			
Hexachlorobenzene (µg/kg ww)	EPA 8270D	20.0	na			

Note: All tissue samples will be analyzed for lipids and total solids. The number of individual specimens comprising each composite sample will be: 5 (Dungeness crab edible meat), 10 (Dungeness crab hepatopancreas, English sole fillet, and English sole whole body), and 15 (shiner surfperch whole body).

[a] Numbers of composite samples are for crab edible meat. The number of hepatopancreas composite samples to be analyzed per analyte is one-half of the number of edible meat composite samples.

[b] If none of the PCB Aroclors are detected in a sample, then the sample will be submitted for analysis of PCB congeners by Method 1668C with an estimated RL of 0.0004 µg/kg.

[c] For English sole,6 fillet and 6 remainder samples will be analyzed in each reach for a total of 12 English sole tissue samples in each reach.

[d] For Dungeness crab, 6 crab edible meat samples and 3 hepatopancreas samples will be analyzed in each reach.

[e] Only whole-body samples of shiner surfperch will be analyzed.

[f] Shiner surfperch from each subarea within a reach will be combined into a single composite sample for these analytes (e.g., shiner surfperch from subreaches 1a and 1b will be combined into a Reach 1 composite sample).

[g] The samples analyzed for PCB congeners represent a minimum of 50% of the composite samples. All of these samples will be analyzed for PCB Aroclors.

[h] The RL cPAH TEQ value was calculated using one-half the RL for each of the cPAH compounds and appropriate TEF values (California EPA 2009).

[i] The dioxin/furan RL is based on the laboratory minimum calibration level from Axys; the dioxin/furan mammalian TEQ value was calculated using one-half the RL for each dioxin/furan compound and appropriate mammal TEF values (Van den Berg et al. 2006).

Axys – Axys Analytical Services, Ltd.
BEHP – bis(2-ethylhexyl) phthalate
BHC – benzene hexachloride
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DDT – dichlorodiphenyltrichloroethane
EPA – US Environmental Protection Agency
na – not available
PCB – polychlorinated biphenyl
PCP – pentachlorophenol
RL – reporting limit
ROD – Record of Decision
SIM – selected ion monitoring
TBT – tributyltin
TEF – toxic equivalency factor
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

Lipids and total solids will also be analyzed in each tissue composite sample. The analytical methods and RLs for the conventional parameters are provided in Appendix B.

All fish composite samples will be analyzed for the same analytes as described above for Dungeness crab, with the exception of cPAHs, which will not be analyzed in fish tissue because they are metabolized (Collier et al. 2013).

In future monitoring events, the target numbers of composite samples may change from the baseline design as a result of updated estimates of mean and variance. The analyte list may change as well.

3.2.3 Clam tissue QAPP

The DQOs for the collection and analysis of LDW clam tissue samples are as follows:

- To establish baseline site-wide 95UCL concentrations of risk drivers for comparison to TTLs for RAO 1
- To calculate baseline site-wide mean clam tissue concentrations to assess trends following sediment remediation for contaminants with TTLs[54]

The clam tissue sampling will also support risk communication related to human health consumption of resident seafood (RAO 1).

3.2.3.1 Study design and rationale

The RI had 12 clam collection areas (Windward 2010a), including two areas in Slip 4; for this study, the two areas in Slip 4 (which has been remediated) will be combined into a single area for a total of 11 clam collection areas. One clam composite sample will be collected from each of the 11 clam collection areas (Map 3-10) where clams are available.[55] Each composite sample will contain 20 to 25 *Mya arenaria* clams collected from each area. The data from all of the clam composite samples will be combined to calculate the site-wide 95UCL for the LDW, as specified in ROD Table 21 (EPA 2014) (see Appendix A for details).

[54] As specified in ROD Table 21, LDW clam target tissue concentrations (EPA 2014)).
[55] Because the areas in Slip 4 and Terminal 117 were remediated in early actions, clams may not be available, in which case no tissue samples would be collected from these areas.

3.2.3.2 Analytical and sampling methods

Clams will be collected by hand using shovels in the same manner as described in the benthic invertebrate QAPP for the RI (Windward 2004b). In brief, clams (*M. arenaria*) will be collected for chemical analyses at low tide following the CPUE method used in 2003 during the clam abundance survey. This method will involve field crew members actively searching for and collecting clams from areas within the intertidal clam tissue collection areas (Map 3-10) with the highest clam abundance, as determined by evidence of shows. At each intertidal area, a total of one composite tissue sample consisting of at least 81 g of clam tissue (excluding shells) will be collected. This composite sample will consist of at least 20 to 25 clams.

Clam composite samples will be analyzed for human health seafood consumption COCs (PCBs, dioxins/furans, cPAHs, and inorganic arsenic) identified in ROD Table 14 (EPA 2014) (Table 3-6). Lipids and total solids will also be analyzed in each composite sample, and PCB congeners will be analyzed in six[56] composite samples in order to calculate PCB TEQs.

Table 3-6. Summary of clam tissue analytes, analytical methods, RL goals and numbers of samples

Analyte	Method	RL Goal	TTL (ROD Table 21)	No. of Composite Samples
Inorganic arsenic (mg/kg ww)	EPA 1632	0.01	0.09	11 main body without siphon skin; 11 siphon skin
Vanadium (mg/kg ww)	EPA 6020A	0.004	na	3
cPAH (µg TEQ/kg ww)	EPA 8270D-SIM	0.025–2.5[a]	0.24	11
Dioxins/furans (ng TEQ/kg ww)	EPA 1613B	0.0000075–0.025[b]	0.71	11
Total PCBs (µg/kg ww)	EPA 8082A (Aroclors)	4[c]	0.42	11
PCB congeners (sum) (µg/kg ww)	EPA 1668C	0.0001	0.42	6
BEHP (µg/kg ww)	EPA 8270D	50.0	na	3
Carbazole (µg/kg ww)	EPA 8270D	20.0	na	3
PCP (µg/kg ww)	EPA 8270D	100	na	3
TBT (µg/kg ww)	EPA 8270D-SIM	3.86	na	3
Aldrin (µg/kg ww)	EPA 8270D/1699 Mod	1.0	na	3
alpha-BHC (µg/kg ww)	EPA 8270D/1699 Mod	1.0	na	3
beta-BHC (µg/kg ww)	EPA 8270D/1699 Mod	1.0	na	3

[56] In addition to the six clam tissue composites to be analyzed for PCB congeners, if none of the PCB Aroclors are detected in a sample, then the sample will be submitted for analysis of PCB congeners. The combination of these methods will ensure that the PCB concentrations are sufficiently sensitive relative to the PCB TTL.

Analyte	Method	RL Goal	TTL (ROD Table 21)	No. of Composite Samples
Total chlordane (µg/kg ww)	EPA 8270D/1699 Mod	2.0	na	3
Total DDTs (µg/kg ww)	EPA 8270D/1699 Mod	2.5	na	3
Dieldrin (µg/kg ww)	EPA 8270D/1699 Mod	1.0	na	3
gamma-BHC (µg/kg ww)	EPA 8270D/1699 Mod	1.0	na	3
Heptachlor (µg/kg ww)	EPA 8270D/1699 Mod	1.0	na	3
Heptachlor epoxide (µg/kg ww)	EPA 8270D/1699 Mod	1.0	na	3
Hexachlorobenzene (µg/kg ww)	EPA 8270D	20.0	na	3

Note: All tissue samples will be analyzed for lipids and total solids.

[a] cPAH TEQ-based RL values for individual cPAH compounds were calculated using RLs and the appropriate TEF values (California EPA 2009). The values for all cPAH compounds are provided in Appendix B.

[b] Dioxin/furan TEQ-based RL values for individual dioxin/furan congeners were calculated using RLs and appropriate mammal TEF values (Van den Berg et al. 2006). The DLs for all dioxin/furan congeners are provided in Appendix B.

[c] If none of the PCB Aroclors are detected in a sample, then the sample will be submitted for analysis of PCB congeners by Method 1668C with an EDL of 0.0001 µg/kg. This estimated EDL is based on the laboratory-estimated DL from Axys and represents the value for an individual PCB congener. Individual congener EDLs are listed in Appendix B. The reported EDLs will vary based on the sample mass and the analytical conditions at the time of analysis.

BEHP – bis(2-ethylhexyl) phthalate
BHC – benzene hexachloride
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DDT – dichlorodiphenyltrichloroethane
DL – detection limit
EDL – estimated detection limit
EPA – US Environmental Protection Agency
na – not available
PCB – polychlorinated biphenyl
PCP – pentachlorophenol
RL – reporting limit
ROD – Record of Decision
SIM – selected ion monitoring
TBT – tributyltin
TEF – toxic equivalency factor
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

In addition to the four human health COCs, to serve as a baseline for long-term monitoring, three clam composite samples will be analyzed for the other chemicals listed in ROD Table 14 (EPA 2014). These chemicals include BEHP, PCP, TBT, vanadium, and organo-chlorine pesticides (Table 3-6). The three clam composite samples analyzed for the COPCs will contain equal portions of tissue from the composite samples from each of the following intertidal segments: RM 0 to RM 1.3 (i.e., clamming areas 1 to 3), RM 1.3 to RM 2.6 (i.e., clamming areas 4 to 6), and RM 2.6 to RM 3.9 (i.e., clamming areas 7 to 11) (Map 3-10). Details regarding the compositing strategy will be presented in the clam tissue QAPP.

The Oregon Department of Environmental Quality (ODEQ) (Oregon DEQ 2015) and RARE clam and arsenic study (Kerns et al. 2017) have reported that *M. arenaria* accumulate a larger fraction of both total and inorganic arsenic in their siphon skin (relative to the rest of the body). Because of this, inorganic arsenic will be analyzed in both siphon skin and the remaining edible clam meat in all of the clam composite samples in the baseline sampling. These data are meaningful from a health advisory perspective as well as to further track if clam tissue minus the siphon skin is

progressing toward the inorganic arsenic TTLs. ODEQ's health advisory states: "the inorganic arsenic found in softshell clams can be greatly reduced by removing the siphon skin before eating, and therefore it is recommended that the siphon skin be removed before consuming."

Based on a recent investigation (Appendix F), the data indicate that cPAHs are not preferentially accumulating in siphon skin relative to the remainder of clam tissue. Therefore, analysis of clam tissues for cPAHs will be performed on composites of whole-body clam tissue that include siphon skin tissue.

3.2.4 Surface water QAPP

The DQOs for the collection and analysis of LDW surface water samples are as follows:

- To assess progress toward water quality applicable or relevant and appropriate requirements (ARARs) as sediment remediation and source control continue
- To establish baseline concentrations to be used to assess trends in PCB concentrations in surface water as sediment remediation and source control continue

3.2.4.1 Study design and rationale

As described in the CSM (Section 1.1.3), it is important to consider how the LDW functions as a tidal estuary with upstream dam control when designing the water sampling program to establish baseline conditions and long-term monitoring.

As is typical of a tidally influenced estuary, a well-defined salt wedge is present in the LDW that can extend from RM 1.8 to beyond RM 5.0, depending on upstream flow and tidal conditions. Also, flow rates in the LDW are variable and can influence water quality. The flow rates are influenced by three main factors: tidal cycles (and their relative magnitude), recent precipitation, and water release rates from the Howard Hanson Dam. These factors intersect to result in a range of river conditions.

The following key factors were considered in the study design, which is presented separately for each DQO:

- Salt wedge and freshwater and saltwater layers within water column
- Different flow rates, storm conditions, and dam releases typically seen in the system
- Tidal cycles

Composite-grab Samples

Spatial Distribution

For spatial coverage, surface water samples will be collected at two locations in the LDW (RM 0.75 and RM 3.3) and one upstream reference location. The upstream reference location will be at RM 10 of the Green River, at the Foster Links Golf course.[57] Because the LDW is a dynamic estuarine system, localized impacts of sediment cleanup activities are not expected to be discernable in the water column. Thus, information related to sediment cleanup is not considered in the selection of sampling locations. Because the available information (as described in Sections 2.2 and 2.3) suggests that surface water is well mixed laterally across the LDW, samples will be collected only in the central portion of the waterway.

Water Column Layers

To evaluate potential differences in concentration between the freshwater (i.e., near-surface) layer and the marine saltwater (i.e., near-bottom) layer of the LDW, each of the two LDW sampling locations will be sampled at two water depths. A near-surface water sample will be collected 1 m below the surface of the water, and a near-bottom water sample will be collected 1 m above the sediment surface (generally representing the marine saltwater layer).[58] A vertical profile of salinity data (and other relevant water quality information) will be recorded during sample collection. The upstream location will be sampled at the midpoint of the water column; near-surface and near-bottom samples will not be needed because of the absence of the marine saltwater layer in this portion of the river and the relatively shallow river depth.

Flow Conditions

The composite-grab sampling events will represent a range of flow conditions in order to characterize chemical concentrations in LDW surface water under a variety of flow conditions. As described in the CSM (Section 2), the targeted flow conditions are anticipated to include the conditions that result in the highest concentrations of chemicals such as PCBs. The following definitions will be used:

- **Storm event** – Precipitation forecasted to be greater than 0.25 in. within a 24-hour period (Storms 1 and 3, Table 3-7) and greater than 0.50 in. within a 24-hour period (Storms 2 and 4, Table 3-7).

[57] This Green River location was selected for consistency with past sampling conducted by USGS and King County.

[58] Samples will be collected regardless of the salinity at the time of sampling. For example, the near-bottom sample may or may not represent the marine layer depending on the location of the salt wedge at the time of sampling.

- **Significant dam release**[59] – A flow rate greater than 2,000 cfs at the USGS gage just below the Howard Hanson Dam (Gage 12105900), which represents the rate of release from the dam.
- **Baseflow** – Average flow rates within wet and dry seasons, measured as rates of discharge at the USGS gage just below the Howard Hanson Dam (i.e., daily averages of approximately 200–600 cfs during the dry summer months and approximately 800–1,200 cfs during the wet winter months).

To assess concentrations within this dynamic system, four sampling efforts will be conducted to target storm events (two with and two without a significant dam release), two sampling events will be conducted to target dry baseflow conditions, and two sampling events will be conducted to target wet baseflow conditions (Table 3-7). These eight sampling events are anticipated to bracket the range of varying conditions in the LDW. Information regarding flow conditions and precipitation will be presented along with the sampling results for each sampling event in the data report.

Table 3-7. Composite-grab sampling events

Sampling Event	Targeted Precipitation[a]	Targeted Dam Release Conditions[b]	Target Schedule
Dry baseflow 1[c]	3-day antecedent period without measurable rainfall	targeting dry season average dam releases (e.g., 200–600 cfs)	August/ September 2017
Storm 1[d]	> 0.25 in. in 24-hour period with 48-hour antecedent period without heavy rainfall[e]	no significant dam release (< 2,000 cfs)	September/ October 2017[f]
Storm 2[d]	> 0.5 in. in 24-hour period with 48-hour antecedent period without heavy rainfall[e]		
Storm 3[d]	> 0.25 in. in 24-hour period	with significant dam release (> 2,000 cfs)	Nov. 2017 to Jan. 2018
Storm 4[d]	> 0.5 in. in 24-hour period		
Wet baseflow 1[c]	3-day antecedent period without measurable rainfall	targeting wet season average dam releases (e.g., 800–1,200 cfs)	Dec. 2017 to March 2018
Wet baseflow 2[c]			
Dry baseflow 2[c]	3-day antecedent period without measurable rainfall	targeting dry season average dam releases (e.g., 200–600 cfs)	July/August 2018

[a] Forecasted precipitation will be based on local rainfall projections from the NOAA weather website. Rainfall prior to sampling (i.e., the antecedent period) will be based on measurements taken at the Hamm Creek gage (HAU2). Details will be provided in the surface water QAPP.

[b] Dam releases are as measured at the USGS gage just below the Howard Hanson Dam (Gage 12105900). Details will be provided in the surface water QAPP.

[c] If possible, dry and wet baseflow sampling will target spring and neap tides (i.e., one dry and one wet baseflow event will be conducted during spring tides, while the other dry and wet baseflow events will be conducted during

[59] Significant dam releases are not defined by USACE. Rather, a significant dam release was defined as a rate greater than 2,000 cfs for consistency with rates used by King County and USGS water sampling programs (King County 2014; USGS 2016, 2017).

neap tides). A spring tide (which occurs just after a new or full moon) is when there is the largest difference between high and low tides, while a neap tide (which occurs halfway between a new and full moon) is when there is the smallest difference between high and low tides.

[d] Samples will be generally collected within 12 hours of the period during a storm that is predicted to have a greater amount of rainfall. Details are provided in the surface water QAPP (Windward 2017b).

[e] During the antecedent 48-hour period, up to approximately 0.2 in. of precipitation will be considered acceptable.

[f] If storm event samples without significant dam release cannot be collected in 2017, attempts will be made in September/October 2018.

cfs – cubic feet per second
EPA – US Environmental Protection Agency
LDWG – Lower Duwamish Waterway Group
NOAA – National Oceanic and Atmospheric Administration
QAPP – quality assurance project plan
USGS – US Geological Survey

Tidal Cycles and Sample Timing

Each composite-grab sample will be a composite of four grab samples collected at least 1 hour apart. This compositing approach will integrate short-term temporal variability to provide a better basis for the evaluation of trends in long-term monitoring.

For dry and wet baseflow sampling events, sampling will be conducted during a consistent portion of the tidal cycle to increase the comparability of these events for long-term monitoring. Thus, for the LDW locations, the sampling period will be approximately centered around a daytime high tide to maximize the residence time of the near-bottom layer and the likelihood of sampling the marine layer at the upper LDW location. The upstream reference location will be sampled during outgoing tide to ensure that all flow is from the Green River Watershed during sampling. Details of the tidal cycle will be recorded during each sampling event.

For storm events, because of the need to target certain precipitation levels and dam release conditions, specific tidal cycles will not be targeted. Tidal conditions at the time of sampling will be documented.

Passive Samplers

This section provides an overview of the sampling design for the passive samplers. In order to provide a baseline dataset for PCBs that can be used to assess long-term trends, it is important to control for as many variables as possible. Thus, the CSM for the LDW was used to reduce the large number of sampling targets (e.g., location, depth, and season) to a reasonable subset that could be measured effectively during baseline sampling, and from which temporal inference could be made. The sampling design for the passive samplers and its rationale are summarized in Table 3-8 (additional details are provided in the surface water QAPP (Windward 2017b)).

Table 3-8. Summary of passive sampler conceptual design and rationale

Design Component	Approach	Rationale
Passive sampler material	PE	PE is the recommended material to be used during passive sampler water column deployments for PCBs, as it allows for sufficient polymer mass to ensure reliable detection (EPA et al. 2017). The passive sampler consists of steel mesh envelopes containing PE strips that are suspended from a frame in the water column.
Deployment duration	1 month	The most chlorinated PCB congeners can take several months to 1 year to fully equilibrate using a PE passive sampler (Tcaciuc et al. 2015). PRCs will therefore be used to correct for non-equilibrium conditions. One month is recommended as a balance between achieving sufficient equilibration within the sampler (to allow for reliable equilibrium corrections using PRC data), and minimizing the potential for sampler loss or biofouling. The 1-month period also integrates and averages the actual short-term variability of PCB concentrations in the water, resulting in a measurement that allows for a more powerful assessment of long-term trends (Windward and Integral 2017a; Appendix A).
Location	2 locations (RM 2.0 and RM 3.3 - South Park Bridge)	These locations have the permanence required to deploy a sampler so that it is less likely to be lost due to vessel traffic. The upstream location provides consistency with the composite grab sample location (RM 3.3), where the near-bottom water is generally within the marine layer during the dry season.[a] The downstream location provides a second location to afford more data within the LDW.
Season	dry baseflow - summer (August)	Based on existing whole-water data and the CSM presented in this work plan, the highest PCB concentrations are expected in the near-bottom water layer during the lower water flows encountered in the dry season. Within-season variability will be minimized by using month-long deployment.
Depth	1 m above sediment	The influence of the sediment remedy is of interest, and therefore the near-bottom layer of water was selected so that the passive sampler more directly represents the water influenced by PCBs flux from sediments than from other sources. This depth also ensures consistent exposure to the water column (i.e., tidal changes make higher elevation deployment more of a concern). Finally, this depth is consistent with the lower collection depth of the composite-grab samples being collected for DQO 1 (see Section 4.1.1.2).
Frequency	samplers deployed in August 2017 and August 2018	Samples will be collected over 2 years to assess 2 dry baseflow periods.
Number of replicates	9 replicates at each location (attached to separate supports)	Nine replicate samplers will be deployed at the same location and during the same sampling event in order to capture the variability of passive sampler analysis (see power analysis [Appendix A]). Six additional samplers (for a total of 15) will be deployed in case any samplers are lost.

[a] The water in the near-bottom layer has longer residence time during low flows, because there is less entrainment into the outflowing surface layer, which reduces the net inflow from Elliott Bay.

CSM – conceptual site model
DQO – data quality objective
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
PE – polyethylene
PRC – performance reference compound
RM – river mile

3.2.4.2 Analytical and sampling methods

Composite-grab Samples

Composite-grab sampling for the two LDW locations will be conducted from a boat. As described, one composite sample representing the near-surface layer and one composite

sample representing the near-bottom layer will be collected at each LDW location. The upstream reference location sampling will be conducted from a bridge; the sample at this location will be collected from the midpoint of the water column.

When collecting each grab sample, conventional water quality parameters will be measured throughout the water column at each location using a multi-meter probe. Water quality parameters will be measured using a multi-parameter water quality meter to record a profile of the entire water column for conductivity, temperature, dissolved oxygen, pH, and turbidity.

Each grab sample will be collected using a Niskin bottle sampler, which will be lowered to the target depth on a line and triggered to close. Four grab samples will be collected at both sampling depths (i.e., near-surface and near-bottom water for the LDW locations) and composited into one sample per depth at each location. Details on the sampling method are provided in the surface water QAPP (Windward 2017b).

The composite-grab samples will be analyzed for analytes included in Washington's water quality standards (Washington Administrative Code [WAC] 173-201A-240), the Washington Toxics Rule (40 Code of Federal Regulations [CFR] 131.45 as applied to Washington[60]), and national recommended ambient water quality criteria (AWQC),[61] with a few exceptions. The ARAR is the most stringent of the water quality criteria (WQC) from Washington Administrative Code 173-201A, NTR (40 CFR 131.45 as applied to Washington), and AWQC values. Volatile organic compounds (VOCs) will not be analyzed in the water samples because these compounds are volatile, rarely detected in surface water samples, and cannot be analyzed in a composite water sample. In addition, VOCs are not LDW COCs or COPCs for human health.

In addition, two organophosphorus pesticides (Demeton and Guthion) and two herbicides (2,4,5-TP and 2,4-D) that have water quality standards will not be analyzed in water samples because they are agricultural compounds that are rarely detected at concentrations above AWQC in water quality monitoring in agricultural areas (Tuttle et al. 2017). None of these analytes were detected in samples collected from the LDW at its confluence with the Black River by King County in 1996. These compounds are not COCs, and there is no indication of a source of these compounds at industrial uses along the LDW; they are generally restricted in use to specific agriculture applications. These pesticides and herbicides are not persistent in the environment, with half-lives on

[60] Washington State criteria include standards promulgated in WAC 173-201A and human health criteria consistent with the Washington Toxics Rule (40 CFR 131.45, as applied to Washington) and 40 CFR 131.36 (d)(14), including the 40 CFR 131 criteria updated on November 28, 2016. These criteria were updated after publication of the ROD.

[61] For the LDW, the relevant and appropriate AWQC for the protection of human health are only those established for the consumption of organisms, because LDW surface water is not a source of potable water, and for those analytes that could come from sediments or lateral sources entering the site. The relevant and appropriate AWQC for the protection of aquatic life are the aquatic marine criteria.

the order of weeks to months (USDA 2016). Guthion and 2,4,5-TP have been banned from use in the United States since 2013 and 1985, respectively.

The specific analytes, analytical methods, and RL goals are provided in Table B-6 of Appendix B. All of the RL goals for metals, except thallium, are below the corresponding WQC. The RL goals for TBT, some SVOCs, and pesticides are higher than the lowest WQC for these compounds. The analytes for which the RL goals are above the lowest criteria value are highlighted in Appendix B. The selected analytical methods are the most sensitive methods available for these analytes.

After the completion of sampling events in 2017 (i.e., the first three sampling events, including the first dry baseflow event and the first two storm events [without significant dam release], as outlined in Table 3-7), the analyte list will be evaluated based on data from these two events, as well as historical water data from the LDW and East Waterway (Windward and Anchor QEA 2014; Windward 2010a). If analytes are not detected or are well below WQC, LDWG will prepare a memorandum for EPA approval indicating which analytes will be deleted from the analyte list for the remaining baseline sampling events and future monitoring.[62] Future monitoring events, to be conducted as part of the long-term monitoring program, may also have fewer sampling locations and depths intervals, depending on the results and objectives of the program.

Passive Samplers

Passive samplers will consist of a stainless steel mesh envelope containing a low-density PE strip attached to a polyvinyl chloride (PVC) frame. The PE strips will be 25 µm thick and cut into 5- × 6-in. strips. The stainless steel mesh envelope will protect the PE strips from loss and damage, and will be customized to fit the PE strips. Passive samplers will be prepared for deployment using methods based on those outlined by (Gschwend et al. 2012).

Passive samplers will be attached to the PVC sampling frame in groups of five for deployment; three sampling frames will be deployed at each location for a total of 15 passive samplers at each location. The deployment frames will be used as the primary structure to suspend the passive samplers in the near-bottom layer of the water column. Anchor weights will be attached across the bottom of the frame to secure the samplers and minimize the agitation of nearby sediment. The loaded frames will then be deployed from a boat by lowering the frames to the sediment surface; they will be secured to the structure's fender boards or pilings when the anchor weights reach the bottom. A multi-parameter data logger will be deployed at the same depth as the passive samplers at each location. The data logger will collect *in situ* water quality data

[62] Organophosphate and carbamate pesticides will be analyzed only in the surface water samples collected during the first storm event.

(e.g., conductivity, temperature, dissolved oxygen, and pH) for the duration of the sampling period.

After approximately 30 days, the passive sampler frames will be retrieved from the site. The PE strips will be extracted and analyzed for PCB congeners. As described in the surface water QAPP, the lowest possible detection limits (DLs) for PCB congeners in surface water based on the results from the PE passive samplers will be calculated based on the laboratory analytical DLs for the PE strips, the partition coefficients between surface water and PE (from Gschwend et al. 2014), and equilibrium assumptions.

3.2.5 Seep QAPP

Seep samples will be collected as part of the pre-design studies to aid Ecology in source identification. Seep sampling will be conducted to determine if groundwater may be a significant ongoing source of contamination in areas where existing groundwater data are insufficient.

Most of the significant seeps in the LDW have been sampled as part of the RI or other programs (Windward 2004a, 2010a). Based on this information, available groundwater information, and a reconnaissance survey, any seep sampling locations will be determined based on the criteria outlined in the flow chart depicted in Figure 3-3.

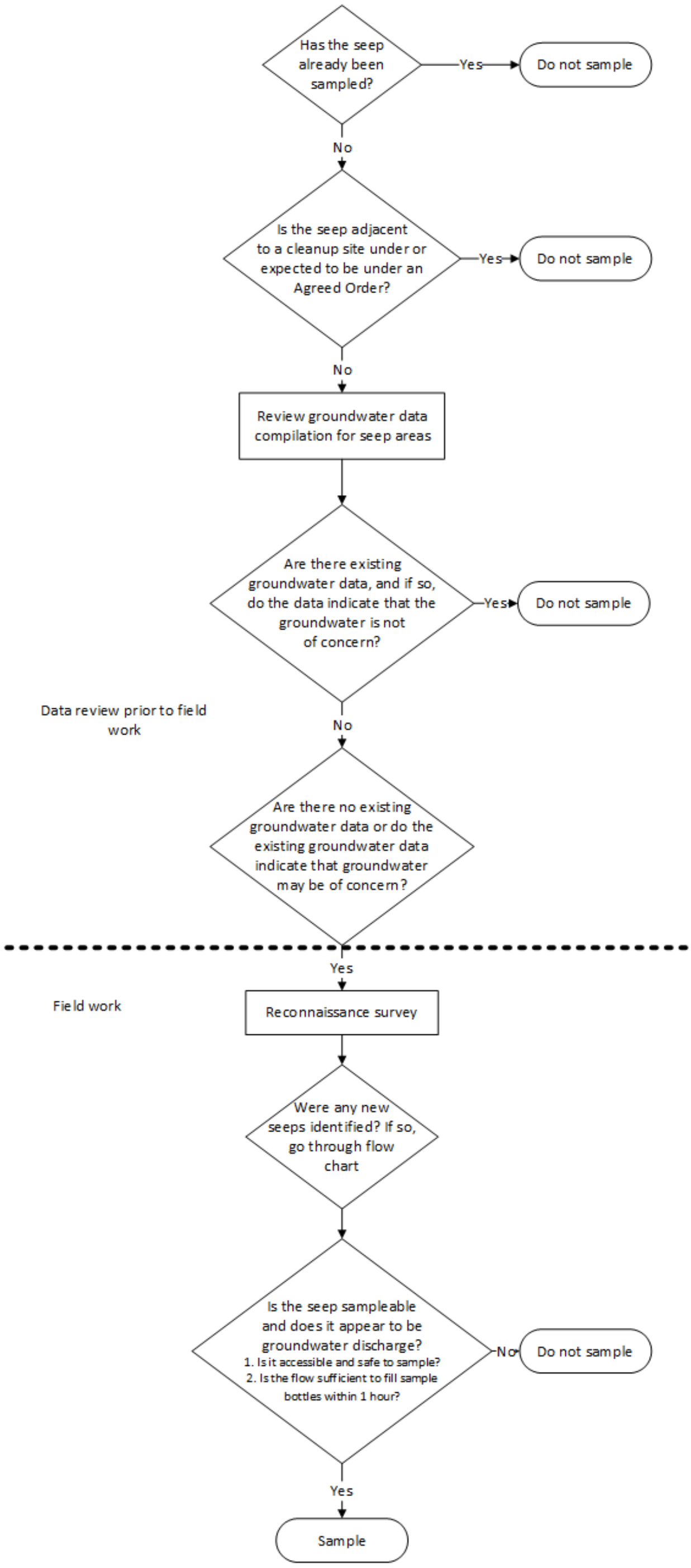


Figure 3-3.Selection criteria to determine if seeps should be sampled

In the seep QAPP, existing data will be reviewed to identify the locations of known seeps, seeps that have been sampled previously, and sites under or expected to be under an Agreed Order. In addition, groundwater data will be reviewed to determine if nearby groundwater data exist, and if so, whether the groundwater data indicates a potential source of recontamination to the LDW. The results of these evaluations will be clearly presented in the seep QAPP.

During the reconnaissance survey (to be conducted several weeks before seep sampling), the field team will look for evidence of flow with sufficient volume to sample. The GPS location of each seep will be recorded and a stake will be used to mark each seep in the field. The temperature and conductivity of each seep of interest will be measured, and locations with less than 30 mS/cm conductivity will be targeted. Qualitative flow rate estimates will be made at each seep using the following categories: high flow (e.g., active flow), medium flow (e.g., smaller stream), or low flow (e.g., trickle). The lowest low tides will be targeted for the reconnaissance survey in order to increase the area of exposed bank and visible beach. The results of the reconnaissance survey will be relayed to EPA via email, and a discussion will be held to agree upon sampling locations. In addition, EPA oversight staff may be present during the reconnaissance to aid in decision making. The sampling will need to occur relatively soon after reconnaissance to take advantage of daylight lowest tides to increase available sampling time. All results will be summarized in the data report.

The sampling methods, the analyte list, and the corresponding analytical methods will be provided in the seep QAPP. The analyte list will include the COCs listed in Tables 19 and 20 of the ROD (EPA 2014).

3.3 TASK 4: SAMPLING AND ANALYSIS

Once the QAPPs (described in Section 3.2) are approved by EPA, field sampling will be conducted and the collected samples will be analyzed according to the QAPP-specific protocols.

Targeted sequencing[63] of the field events is presented in Figure 3-4 and summarized as follows.

- Fish and crab sampling will be conducted in August/September 2017 to match the sampling period in the RI (Windward 2010a).
- Multiple surface water sampling events will be conducted targeting a range of flow conditions, starting in the dry season of 2017 and concluding in 2018.
- Surface sediment sampling (0–10 cm) and source-related sampling near outfalls[64] will be conducted in February or March 2018.

[63] The actual dates are subject to change depending on approval dates of the QAPPs.

- Clam tissue, intertidal sediment (0–45 cm), banks, and seeps will be sampled in May and June 2018 during low tides to allow the greatest extent of the intertidal area to be sampled.

[64] Collection of some source-related sediment samples may be delayed to May/June 2018 if it is determined that low-tide conditions would facilitate the collection of specific samples.

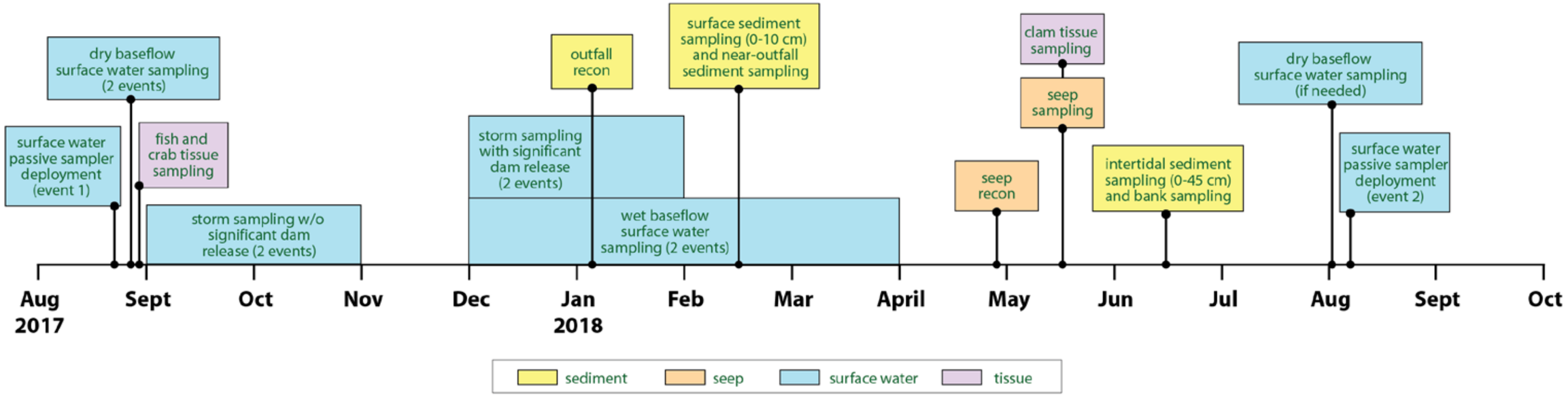


Figure 3-4. Targeted sampling timeline

3.4 TASK 5: SAMPLING DATA REPORTS

Under Task 5, six data reports will be prepared after the completion of each of the following sampling events. Specifically, the following data reports will be prepared:

- Sediment (LDW-wide 0–10-cm samples and near-outfall source identification samples)
- Intertidal sediment (0–45 cm) and banks
- Fish and crab tissue
- Clam tissue
- Seeps
- Surface water (while there will just be one data report [with all water data], validated data will be submitted to EPA after each interim sampling event)

The data reports will contain validated data in tabulated format,[65] data validation reports, laboratory data reports, field forms, and photographs documenting the work conducted. Any deviations from the QAPPs will also be documented. Data will be submitted in electronic data deliverable format to EPA and uploaded to both EIM and SCRIBE. Some portions of data report (e.g., laboratory data reports) will only be submitted in electronic format to conserve natural resources.

Maps in the data report will only include sample locations (including trawl and crab pot locations); data will be mapped in the data evaluation report (Task 6, Section 3.5). All data interpretation, including the calculation of 95UCLs, will be conducted as part of the data evaluation report.

3.5 TASK 6: DATA EVALUATION REPORT

In Task 6, the results of the pre-design study sampling data will be evaluated as described below. One data evaluation report will cover the results of all pre-design investigations included in Task 4 of this work plan. Specifically, the data evaluation report will:

- Specify whether the data collected in Task 4 met DQOs outlined in the QAPPs.
- Provide tables, maps, results of statistical analyses (such as 95UCLs), supporting calculations, and narrative interpretation of baseline data relative to cleanup levels in ROD Tables 19 and 20, surface water ARARs, and TTLs presented the ROD Table 21 (EPA 2014).

[65] Data tables will include maximum, minimum, mean, and frequency of detection.

- Develop SWACs using baseline[66] data for all contaminants with site-wide cleanup levels for surface sediment (0–10cm), and compare these values with RI/FS pre-EAA SWACs and bed composition model (BCM) post-EAA model prediction.
- Compare BCM input parameters from the FS (bed replacement and upstream and lateral chemistry values) against available results[67] for these inputs, and make recommendations for revised input parameters that may be used in future modeling to refine natural recovery predictions.
- Prepare GIS maps with the following layers to be posted on the LDWG website: RI/FS data, Task 4 data, and Task 2 sediment data.
- Provide an assessment of the porewater data collected, as outlined in the porewater addendum to this work plan (Appendix E).
- Identify data gaps and issues, and present recommendations to resolve any gaps or issues requiring additional field characterization or other work.
- Compile a list of any new datasets added to the LDW database since the Task 2 data compilation.

The report will be prepared following submittal of all draft data reports, with the exception of the surface water data report. The surface water data will be evaluated in an addendum to the data evaluation report.

In addition, if requested, LDWG will support EPA in making the GIS maps accessible via the Internet.

3.6 TASK 7: WORK PLAN FOR WATERWAY USER SURVEY AND ASSESSMENT OF IN-WATER STRUCTURES

Under Task 7, a separate work plan was prepared for the waterway user survey and assessment of in-water structures. The Task 7 draft work plan was approved by EPA on April 19, 2017 (Integral and Windward 2017). That work plan provides details for Tasks 7 and 8, including the roles, responsibilities, and approach for conducting the survey and assessment, the data compilation and reporting procedures, and the schedule for completing the work.

In brief, the main objective of the survey and assessment is to gather information that will inform recovery category recommendations and technology assignments (EPA 2016). The survey and assessment will focus on the collection of data related to the physical conditions of the waterway—one of three lines of evidence (LOEs) considered in the determination of recovery categories in the ROD (EPA 2014). The remaining two LOEs (sediment transport and contaminant trend characteristics) will be reviewed, as

[66] Baseline data are defined as those collected to characterize baseline in Task 4 of this work plan.
[67] Available results include the data gathered as part of Tasks 2 and 4, which include updates from EIM.

needed, during design. Final technology assignments will also be determined during design, based on decision criteria identified in the ROD.

3.7 TASK 8: REPORT FOR WATERWAY USER SURVEY AND ASSESSMENT OF IN-WATER STRUCTURES

Under Task 8, the survey and assessment described in the Task 7 work plan (Integral and Windward 2017) will be implemented, and a report that summarizes the activities and results will be prepared. The Task 7 work plan provides the details of the scope and approach. The report will support the development of recovery category recommendations, which are described as Task 9 (Section 3.8).

3.8 TASK 9: RECOVERY CATEGORY RECOMMENDATIONS REPORT

The purpose of Task 9, the recovery category recommendations report, is to assess the recovery category designations presented in the ROD (EPA 2014) and provide recommended modifications, if necessary, based on the findings of the survey and assessment. In this task, the recovery categories map from the ROD will be updated with information collected during Task 8 related to waterway uses and associated in-water structures. The revised map will include annotations that summarize the basis for any proposed recovery category modifications.

The LDW FS (AECOM 2012) defined recovery categories to facilitate the assignment of RALs and remedial technologies to specific areas of the site. The recovery categories were developed based on the potential for contaminant concentrations in sediment to be reduced through natural recovery, or for subsurface contamination to be exposed at the surface due to physical processes (i.e., erosion and scour). Based on the recovery category designations, capping and dredging were assigned to areas with less potential for natural recovery and a higher likelihood of disturbance. ENR and MNR were assigned to areas where recovery is predicted to occur and disturbance is less likely.

The recovery category designations and the criteria used to develop them are presented in Table 3-9 (adapted from ROD Table 23[68] (EPA 2014)). Recovery categories were assigned in the FS (AECOM 2012) by mapping physical criteria and chemistry trend information. Physical criteria included bathymetric evidence of vessel-induced scour, the presence of berthing areas, and modeled predictions of high-flow-induced scour and long-term sedimentation. Temporal contaminant trends were evaluated by reviewing COC concentrations at reoccupied surface sediment sampling locations and vertical profiles of COC concentrations in cores.

[68] ROD Table 23 is titled *Criteria for assigning recovery categories.*

Table 3-9. Recovery category designation criteria

Criteria		Category 1 – Recovery Presumed to be Limited	Category 2 – Recovery Less Certain	Category 3 – Predicted to Recover
Physical criteria				
Physical conditions	vessel scour	observed vessel scour	no observed vessel scour	
	berthing areas	berthing areas with vessel scour	berthing area without vessel scour	not in a berthing area
STM	STM-predicted 100-year high-flow scour	> 10 cm	< 10 cm	
	STM-derived net sedimentation	net scour	net sedimentation	
Rules for applying criteria		If an area is in Category 1 for any one criterion, that area is designated Category 1.	If conditions in an area meet a mixture of Category 2 and 3 criteria, that area is designated Category 2.	An area is designated Category 3 only if it meets all Category 3 criteria.
Empirical contaminant trend criteria – used on a case-by-case basis to adjust recovery categories that would have been assigned based on physical criteria				
Resampled surface sediment locations		If increasing PCB or increasing concentrations of other detected COCs exceed the SCO (> 50% increase), the area is designated Category 1.	If equilibrium and mixed (increases and decreases) results are detected (for COCs that exceed the SCO), the area is designated Category 2.	If decreasing concentrations (> 50% decrease) or mixed results (decreases and equilibrium) are detected, the area is designated Category 3.
Sediment cores (top 2 sample intervals in upper 60 cm)				

Source: Adapted from ROD Table 23 (EPA 2014).

COC – contaminant of concern
PCB – polychlorinated biphenyl
ROD – Record of Decision
SCO – sediment cleanup objective
STM – sediment transport model

The data collected in Task 8 will inform the "physical conditions" in Table 3-9 relating to vessel scour and berthing areas. While direct observation or modeling of vessel scour will not be performed as part of this task, the data gathered under Task 8 will facilitate the identification of areas potentially subject to scour or other disturbances based on current vessel movement patterns and berthing operations. These potential scour areas will then be overlain on the recovery category map (Figure 12 of the ROD (EPA 2014)[69]) to assess where adjustment may be needed, and to focus on any supporting location-specific investigations or analyses that may be needed during design.

The recommendations developed in the recovery category recommendations report will be based on the physical conditions findings of the survey and assessment. This report will be written before the results of the baseline and source-related sampling are available. Therefore, additional data (beyond what was used for the FS (AECOM 2012))

[69] ROD Figure 12 is titled *Recovery Category Areas*.

to inform the "empirical contaminant trend" criteria will be limited to those compiled as part of the Task 2 data compilation. The remedial design data will be used to delineate the boundaries of remedial technologies and to finalize recovery category areas.

3.9 TASK 10: DESIGN STRATEGY RECOMMENDATIONS REPORT

The purpose of the design strategy recommendation report is to develop a conceptual approach and schedule for acquiring the data needed to complete the design for the LDW selected remedy.

The pre-design studies presented in this work plan represent data gathering efforts to establish baseline site conditions, inform the design phase, and assist in gathering source control sufficiency data for Ecology.

As part of design, location-specific environmental and physical data will be collected. Environmental data (e.g., surface and subsurface sediment chemistry) will be collected to refine remedial boundaries and technology assignments; these data will also be used to support other aspects of the design (e.g., cap modeling). Physical data (e.g., sediment geotechnical properties and bathymetry) will be collected to support design elements such as dredge prism and cap designs. In addition, certain planning information will be collected to support the logistical aspects of remedy implementation, including details vital to accommodating waterway users who may be affected by construction activities.

A detailed list of the various data needs for the design phase is presented in Appendix D. This list includes various data objectives, data types, collection methods, and timing considerations.

In preparing this list, thought was given to whether any time-critical data needs exist (beyond those addressed by the efforts that are currently underway) that should be addressed or initiated before the design phase in order for the LDW remedy process to proceed in a timely fashion. Based on the evaluation done for this work plan and the state of practice for phasing large remediation projects, LDWG believes that there are no additional collection efforts that would normally precede the collection of location-specific environmental and physical data. In other words, the collection of such data is the next critical path step in the design process. The design strategy report and discussions preceding it will present additional details about how design data collection efforts will be implemented efficiently to allow for the timely implementation of the remedy. There may be segregable design tasks that can be completed ahead of the critical path tasks, if appropriate.

The design strategy report will describe the purpose and type of data needed to complete the various aspects of the design. The report will also provide a recommended strategy for timing and phasing of the design phase investigation activities, and will describe in greater detail the types of information typically generated by the construction contractor (and detailed in the remedial action work plan), such as transloading facility locations and operations, equipment types, haul routes, cap

material sources, vessel management plans, tribal fishing coordination, detailed schedules, and hours of operation.

The design strategy report will also include a work breakdown structure, which will identify data collection activities required for each element of the design. For instance, the steps required to complete cap designs will be listed in order to identify all of the associated data needs. The other technology-specific and logistical elements of the engineering design will be similarly addressed. A conceptual schedule will be developed to illustrate the timing and sequencing of the corresponding data collection activities.

4 Schedule and Deliverables

Table 4-1 summarizes deliverables and their schedule based on requirements outlined in the third AOC amendment (EPA 2016). Numerous deliverables are being produced as part of the pre-design studies, including various QAPPs, data reports, and evaluation and strategy reports. The project schedule presented in Table 4-1 lists the deliverables that are required to complete the 10 tasks addressed in this work plan. Approval of this work plan is a key element in the linked schedule.

Numerous draft deliverables have already been submitted to EPA, as well as three final deliverables (Table 4-1).

Because many of the dates in the linked schedule are contingent, should a given date not be met, the delivery dates for linked deliverables will be shifted accordingly. In addition, dates beyond the submittal of draft documents are approximate and are dependent on the time required for receipt of EPA comments and resolution of any issues identified in the draft documents. Following the initial draft, EPA comments will be addressed in a revised report due 30 working days from LDWG receipt of EPA comments, unless otherwise approved or directed by EPA.

Table 4-1. Task deliverable schedule

Task No.	Description	Deliverable	Submittal Date to EPA
1	Work plan	annotated outline	Annotated outline is due 210 days from effective date of the third AOC amendment (submitted November 22, 2016).
		draft work plan	Draft work plan is due 60 days from EPA comments on the outline (submitted February 21, 2017).
		draft porewater addendum	Draft addendum due 45 days after submittal of draft work plan (submitted April 17, 2017).
2	Existing data compilation	draft technical memorandum	Draft memorandum is due 255 days from effective date of the AOC third amendment (draft submitted January 6, 2017; draft final submitted March 13, 2017).
		draft groundwater data compilation	Draft groundwater data compilation due 45 days following receipt of EPA comments on the Task 2 data compilation memorandum (submitted March 22, 2017).
3	QAPPs[a]	draft fish and crab tissue QAPP	Draft QAPP is due 45 days after EPA approval of the Task 1 work plan.[a]
		draft sediment QAPP	Draft QAPP is due 45 days after EPA approval of the Task 1 work plan.
		draft clam tissue QAPP	Draft QAPP is due 89 days after EPA approval of the Task 1 work plan.
		draft surface water QAPP	Draft QAPP is due 45 days after EPA approval of the Task 1 work plan.[b]
		draft seep QAPP	Draft QAPP due 68 calendar days after EPA approval of the Task 1 work plan.
4	Sampling and analysis	not applicable	Initiate and complete sampling per approved QAPP schedule.
5	Sampling data reports	draft fish and crab tissue data report	Draft data report is due 21 days after receipt of validated data.
		draft sediment data report	Draft data report is due 21 days after receipt of validated data.
		draft clam tissue data report	Draft data report is due 21 days after receipt of validated data.
		draft surface water data report	Draft data report is due 21 days after receipt of validated data (each round).
		draft seep data report	Draft data report is due 21 days after receipt of validated data.
6	Data evaluation report	draft report	Draft data evaluation report is due 60 days after submittal of draft sampling data report.[c]
7	Work plan for waterway user survey and assessment of in-water structures	draft work plan	Draft work plan is due 225 days after effective date of the AOC third amendment.[d]
8	Report for waterway user survey and assessment of in-water structures	draft report	Initiate survey within 30 days of EPA approval of Task 7 work plan. Draft report is due 45 days after completion of Task 8 survey.

Table 4-1. Task deliverable schedule

Task No.	Description	Deliverable	Submittal Date to EPA
9	Recovery category recommendations report	draft report	Draft report is due 45 days after approval of the Task 8 report.
10	Design strategy recommendation report	draft report	Draft report is due 60 days after submittal of the draft Task 8 report.

[a] The draft fish/crab QAPP was submitted on May 12, 2017; the QAPP was approved by EPA on July 13, 2017.

[b] The draft surface water QAPP was submitted on June 19, 2017; the QAPP was approved by EPA on August 2, 2017.

[c] There will be a series of data reports; the data evaluation report will be submitted following submittal of all of the draft data reports, except for the surface water data report (these results will be evaluated in an addendum).

[d] The draft Task 7 work plan was submitted on December 7, 2016; the work plan was approved by EPA on April 19, 2017.

AOC – Administrative Order on Consent

EPA – US Environmental Protection Agency

LDWG – Lower Duwamish Waterway Group

QAPP – quality assurance project plan

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Harbor I.

Kellogg I.

Slip 1

Slip 2

Slip 3

Slip 4

Slip 6

Upper Turning Basin

MIDDLE PANEL MATCH LINE

LEFT PANEL MATCH LINE

MATCH LINE MIDDLE PANEL

MATCH LINE RIGHT PANEL

- Conceptual baseline surface sediment location (0-10 cm)
- Individual location for RAO 3 evaluation (random location in MNR area)
- Individual location for RAO 3 evaluation (re-occupation of SCO exceedance in RI/FS dataset)
- Conceptual sampling area
- Early Action
- LDW Superfund Boundary
- Navigation Channel
- River mile

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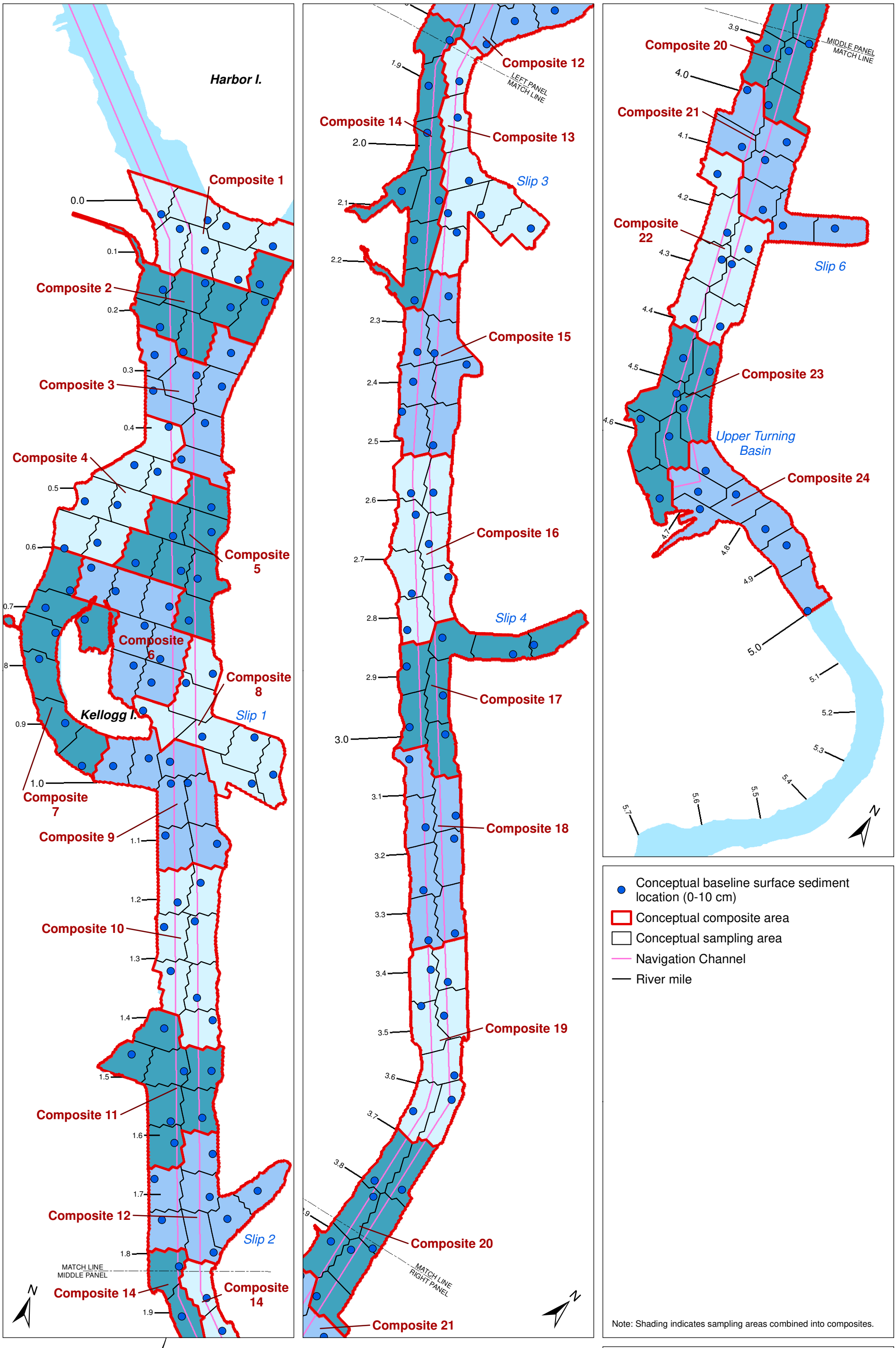
0 0.1 0.2 Miles

0 0.2 0.4 Kilometers

Scale is the same for each inset map

Map 3-1. Conceptual baseline surface sediment (0-10 cm) sampling locations

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-01 6518 Surface sediment sampling plan .mxd



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Map 3-2. Conceptual baseline surface sediment (0-10 cm) composite locations

Harbor I.

Kellogg I.

Slip 1

Slip 2

Slip 3

Slip 4

Slip 6

Upper Turning Basin

LEFT PANEL MATCH LINE

MIDDLE PANEL MATCH LINE

MATCH LINE MIDDLE PANEL

MATCH LINE RIGHT PANEL

- Conceptual baseline surface sediment location (0-10 cm)
- Individual location for RAO 3 evaluation (random location in MNR area)
- Individual location for RAO 3 evaluation (re-occupation of SCO exceedance in RI/FS dataset)
- Conceptual sampling area
- Conceptual composite area

Technology assignment (ROD Fig. 18)

- Dredge
- Partial Dredge and Cap
- Cap
- ENR/*in situ*
- Monitored Natural Recovery (Surface Sediment >SQS)
- Monitored natural recovery (Surface sediment <SQS)
- EAA
- Navigation Channel
- River mile

0 0.1 0.2 Miles

0 0.2 0.4 Kilometers

Scale is the same for each inset map

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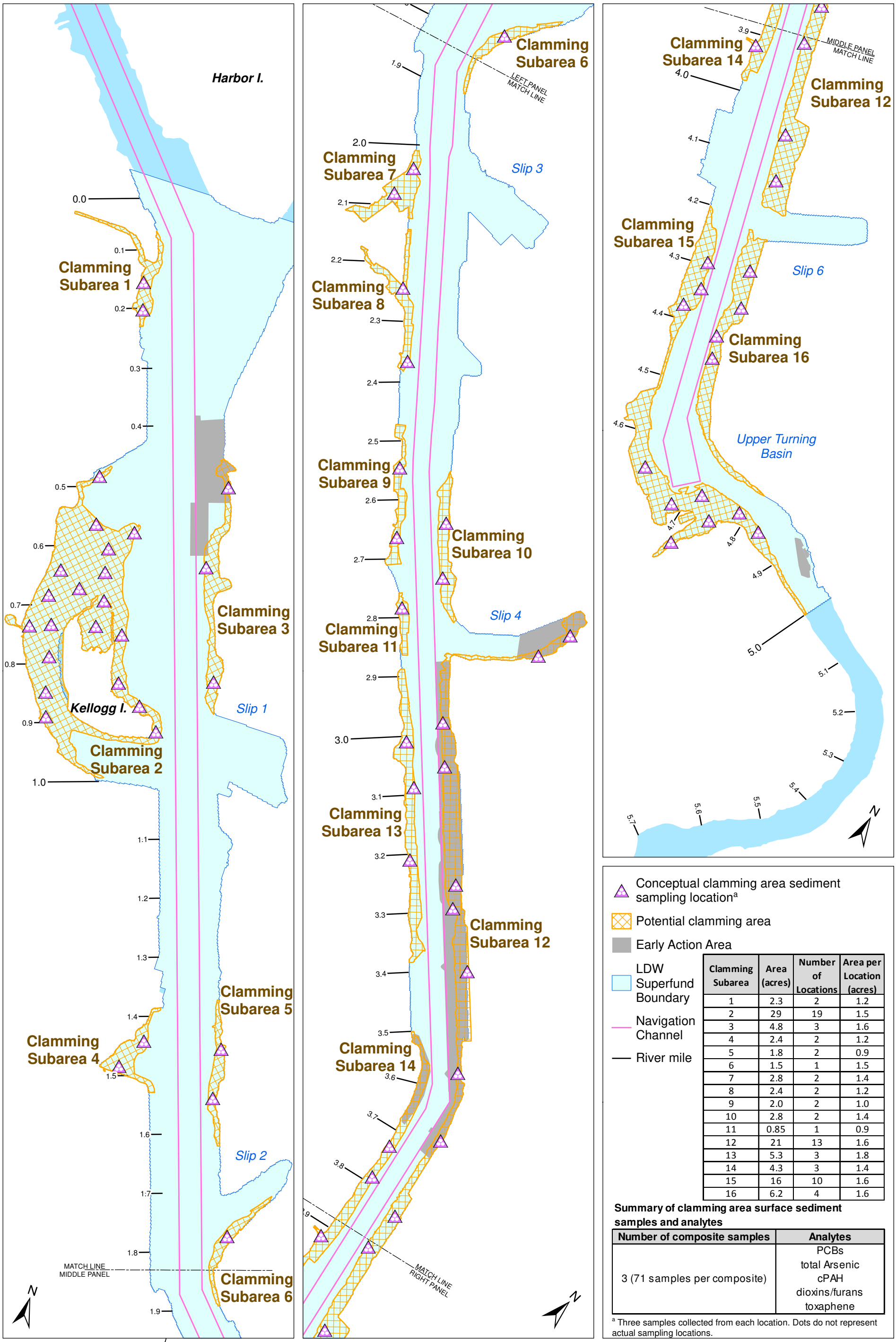
Map 3-3. Conceptual baseline surface sediment (0-10 cm) sampling locations with technology assigments (ROD Fig. 18)

Prepared by craigh, 8/29/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-03 6518 Surface sediment sampling plan wRemedy.mxd



Conceptual clamming area sediment sampling location[a]

Potential clamming area

Early Action Area

LDW Superfund Boundary

Navigation Channel

River mile

Clamming Subarea	Area (acres)	Number of Locations	Area per Location (acres)
1	2.3	2	1.2
2	29	19	1.5
3	4.8	3	1.6
4	2.4	2	1.2
5	1.8	2	0.9
6	1.5	1	1.5
7	2.8	2	1.4
8	2.4	2	1.2
9	2.0	2	1.0
10	2.8	2	1.4
11	0.85	1	0.9
12	21	13	1.6
13	5.3	3	1.8
14	4.3	3	1.4
15	16	10	1.6
16	6.2	4	1.6

Summary of clamming area surface sediment samples and analytes

Number of composite samples	Analytes
3 (71 samples per composite)	PCBs total Arsenic cPAH dioxins/furans toxaphene

[a] Three samples collected from each location. Dots do not represent actual sampling locations.

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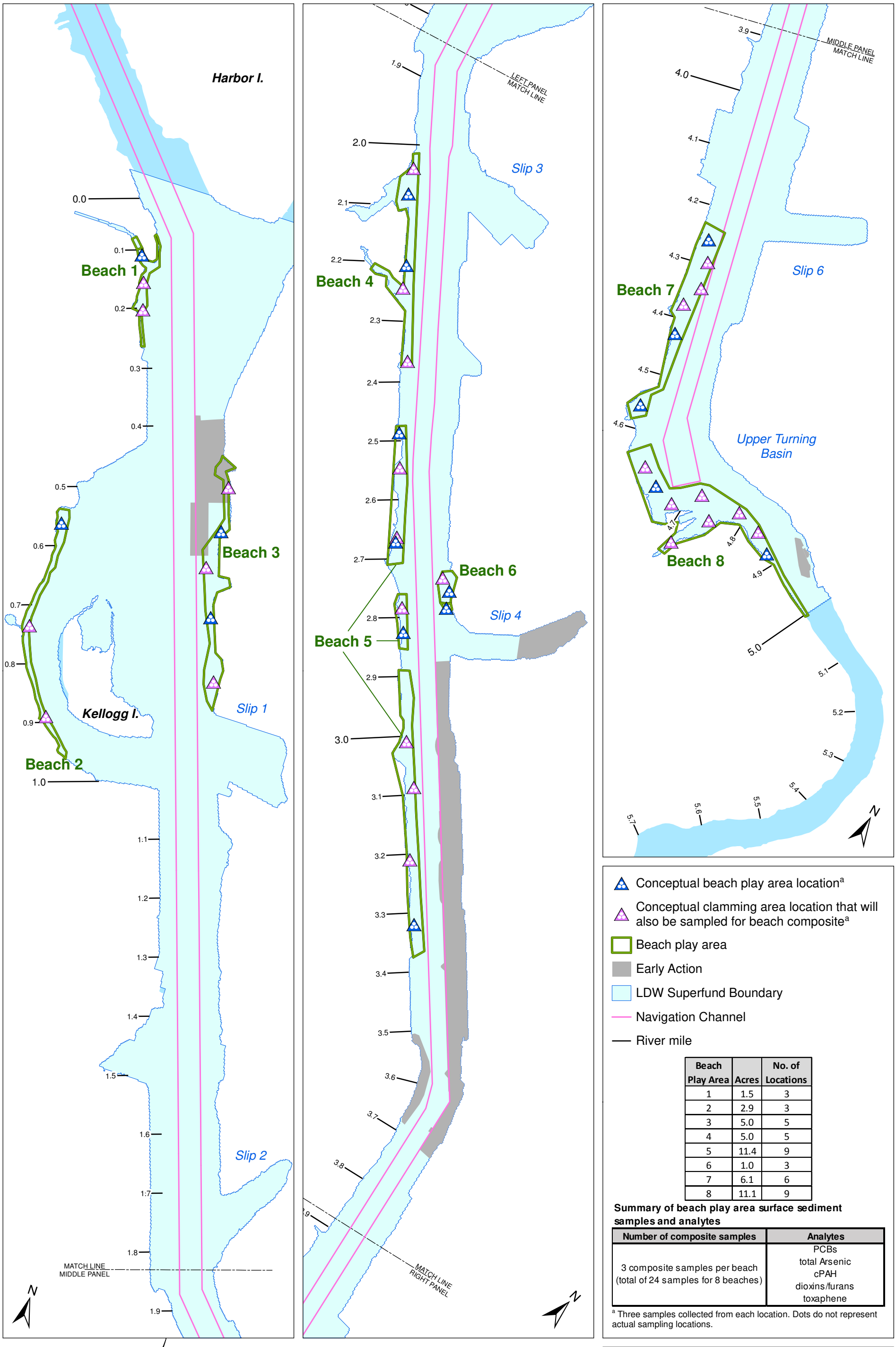
0 0.1 0.2 Miles

0 0.2 0.4 Kilometers

Scale is the same for each inset map

Map 3-4. Conceptual baseline clamming area and surface sediment (0-45 cm) sampling locations

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-04 6517 Intertidal sampling plan-w sampling locs.mxd



Beach Play Area	Acres	No. of Locations
1	1.5	3
2	2.9	3
3	5.0	5
4	5.0	5
5	11.4	9
6	1.0	3
7	6.1	6
8	11.1	9

Summary of beach play area surface sediment samples and analytes

Number of composite samples	Analytes
3 composite samples per beach (total of 24 samples for 8 beaches)	PCBs total Arsenic cPAH dioxins/furans toxaphene

[a] Three samples collected from each location. Dots do not represent actual sampling locations.

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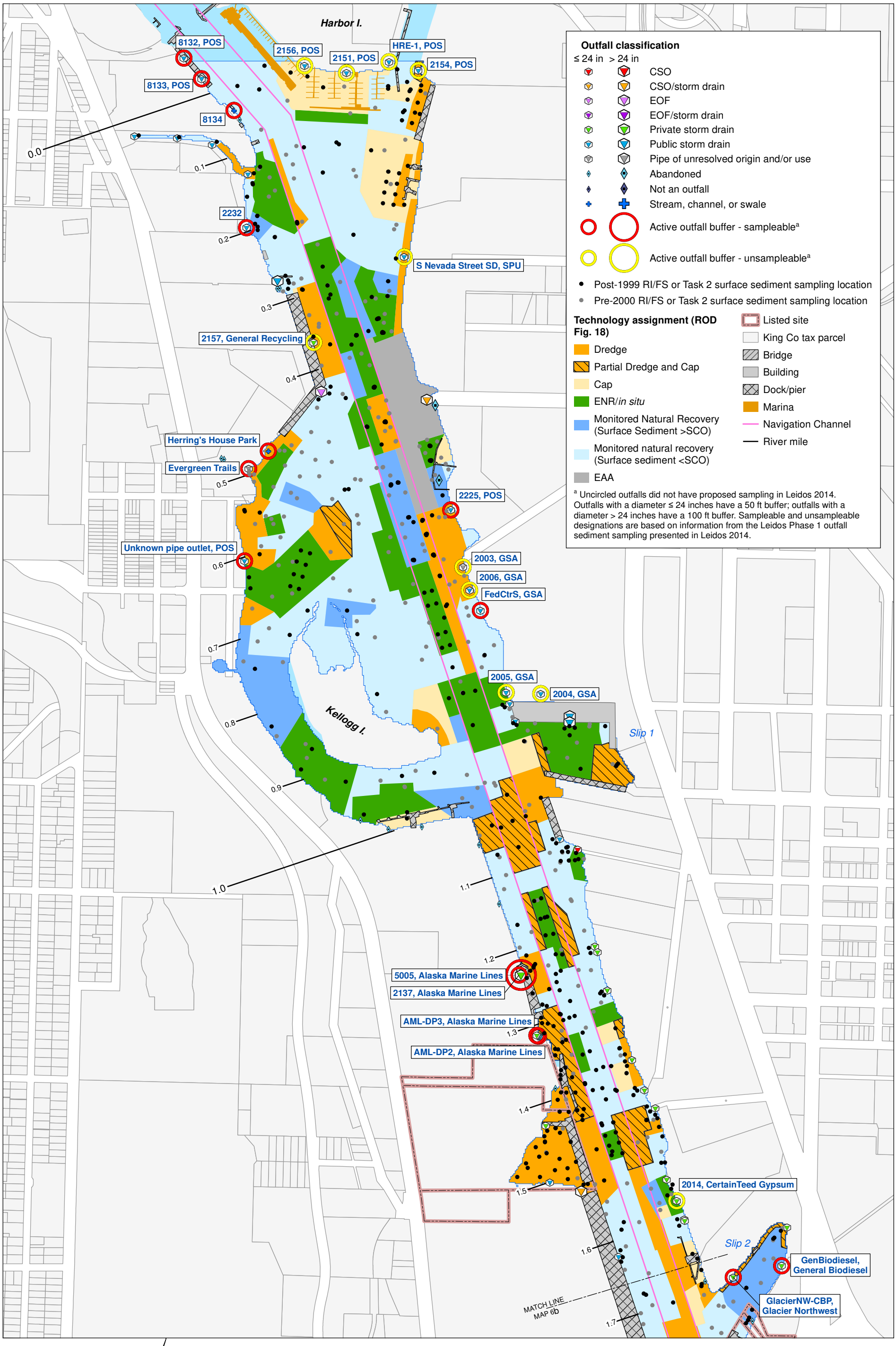
0 0.1 0.2 Miles

0 0.2 0.4 Kilometers

Scale is the same for each inset map

Map 3-5. Conceptual baseline beach play area surface sediment (0-45 cm) sampling locations

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-05 6517 Intertidal sampling plan-w beach locs.mxd



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N

0 0.1 0.2 Miles

0 0.1 0.2 Kilometers

Map 3-6a. Potential target outfalls for nearby sediment sampling, RM 0.0 to RM 1.7

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-06a 6571a Active outfalls.mxd

MAP 6a MATCH LINE

1.7

Slip 2

GlacierNW-CBP, Glacier Northwest

GenBiodiesel, General Biodiesel

2220, POS

1.8

2123, POS

2124, POS

1.9

1st Ave S Bridge SD, WSDOT

2.0

SCS Refd Services, Seattle Cold Storag

2505, WSDOT

2507, WSDOT

2509, WSDOT

Seattle Dist Ctr

2.1

2025

Slip 3

2510, WSDOT

2.2

Dawn Foods, Dawn Foods

2.3

2116, River View Marina

2.4

2114, Boyer Towing

5th Avenue S Ditch, SDOT

2.5

2.6

S Webster St SD, SPU

CleanScapes B, Puget Sound Truck Lines

2.7

2.8

Slip 4

2052, Boeing – Plant 2

2.9

2110, Independent Metals

2109, Independent Metals

3.0

3.1

MATCH LINE MAP 6C

3.2

3.3

16th Ave S Bridge (west), WSDOT

Outfall classification

≤ 24 in	> 24 in	
		CSO
		CSO/storm drain
		EOF
		EOF/storm drain
		Private storm drain
		Public storm drain
		Pipe of unresolved origin and/or use
		Abandoned
		Not an outfall
		Stream, channel, or swale
		Active outfall buffer - sampleable[a]
		Active outfall buffer - unsampleable[a]

- Post-1999 RI/FS or Task 2 surface sediment sampling location
- Pre-2000 RI/FS or Task 2 surface sediment sampling location

Technology assignment (ROD Fig. 18)

- Dredge
- Partial Dredge and Cap
- Cap
- ENR/*in situ*
- Monitored Natural Recovery (Surface Sediment >SCO)
- Monitored natural recovery (Surface sediment <SCO)
- EAA

- Listed site
- King Co tax parcel
- Bridge
- Building
- Dock/pier
- Marina
- Navigation Channel
- River mile

[a] Uncircled outfalls did not have proposed sampling in Leidos 2014. Outfalls with a diameter ≤ 24 inches have a 50 ft buffer; outfalls with a diameter > 24 inches have a 100 ft buffer. Sampleable and unsampleable designations are based on information from the Leidos Phase 1 outfall sediment sampling presented in Leidos 2014.

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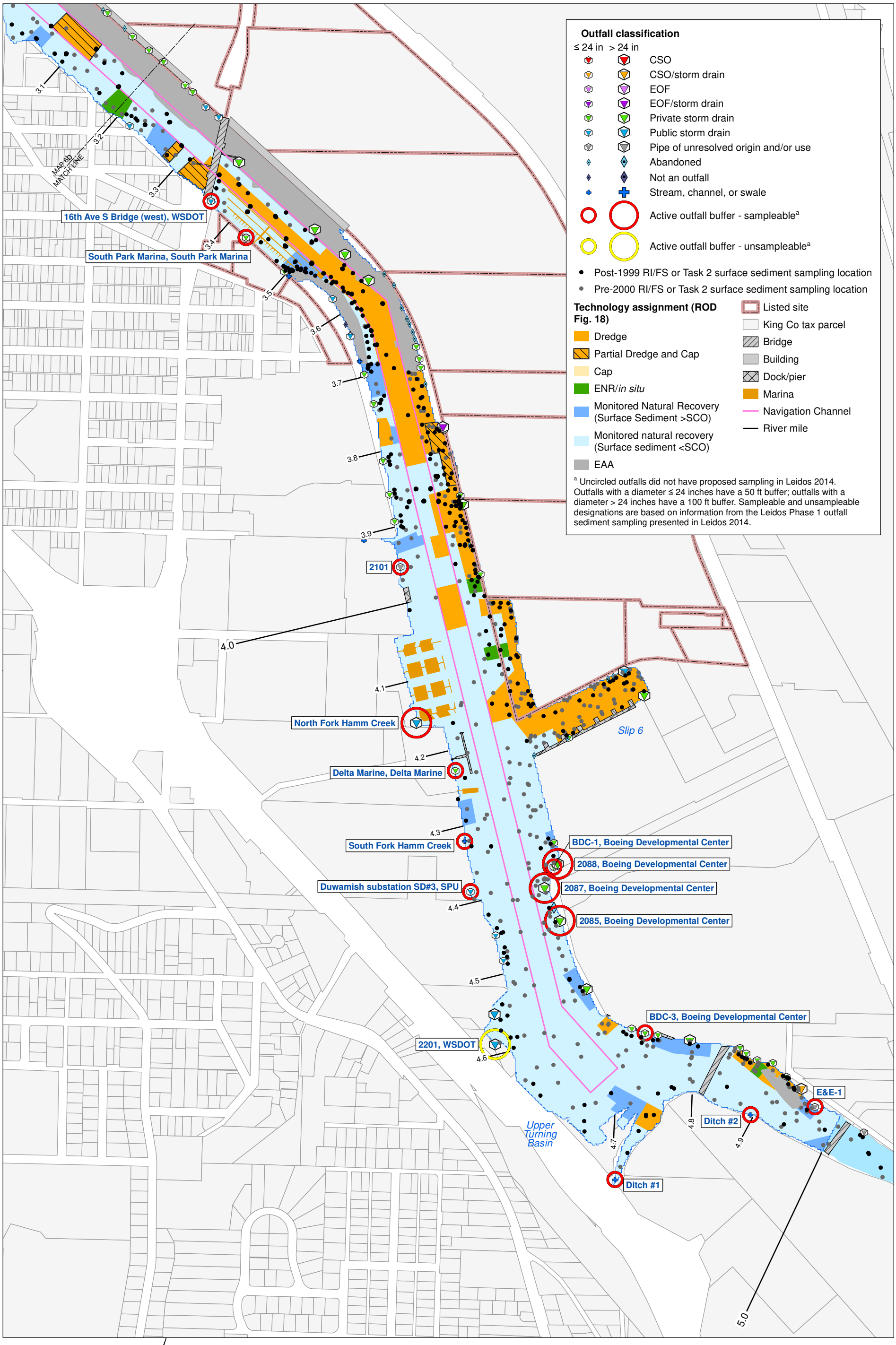
0 0.1 0.2 Miles

0 0.1 0.2 Kilometers

Map 3-6b. Potential target outfalls for nearby sediment sampling, RM 1.7 to RM 3.3

Prepared by craigh, 8/28/2017: W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-06b 6571b Active outfalls.mxd


Outfall classification
≤ 24 in
> 24 in
CSO
CSO/storm drain
EOF
EOF/storm drain
Private storm drain
Public storm drain
Pipe of unresolved origin and/or use
Abandoned
Not an outfall
Stream, channel, or swale
Active outfall buffer - sampleable[a]
Active outfall buffer - unsampleable[a]
Post-1999 RI/FS or Task 2 surface sediment sampling location
Pre-2000 RI/FS or Task 2 surface sediment sampling location
Technology assignment (ROD Fig. 18)
Dredge
Partial Dredge and Cap
Cap
ENR/in situ
Monitored Natural Recovery (Surface Sediment >SCO)
Monitored natural recovery (Surface sediment <SCO)
EAA
Listed site
King Co tax parcel
Bridge
Building
Dock/pier
Marina
Navigation Channel
River mile
[a] Uncircled outfalls did not have proposed sampling in Leidos 2014. Outfalls with a diameter ≤ 24 inches have a 50 ft buffer; outfalls with a diameter > 24 inches have a 100 ft buffer. Sampleable and unsampleable designations are based on information from the Leidos Phase 1 outfall sediment sampling presented in Leidos 2014.
MAP 6D MATCH LINE
3.1
3.2
3.3
16th Ave S Bridge (west), WSDOT
3.4
South Park Marina, South Park Marina
3.5
3.6
3.7
3.8
3.9
2101
4.0
4.1
North Fork Hamm Creek
Slip 6
4.2
Delta Marine, Delta Marine
4.3
South Fork Hamm Creek
BDC-1, Boeing Developmental Center
2088, Boeing Developmental Center
Duwamish substation SD#3, SPU
2087, Boeing Developmental Center
4.4
2085, Boeing Developmental Center
4.5
BDC-3, Boeing Developmental Center
2201, WSDOT
4.6
E&E-1
Upper Turning Basin
4.7
4.8
Ditch #2
4.9
Ditch #1
5.0
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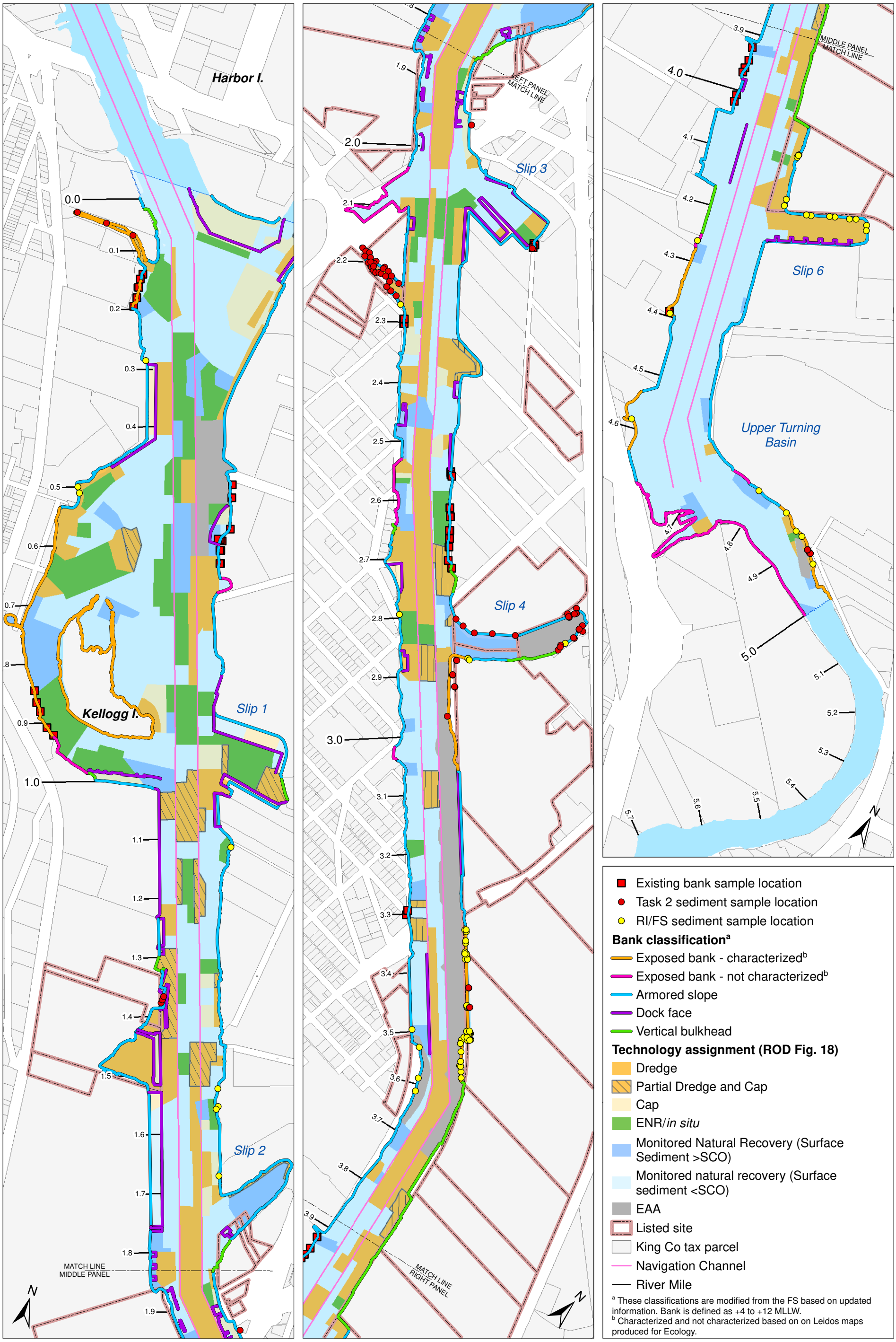
N
0 0.1 0.2 Miles
0 0.1 0.2 Kilometers
Map 3-6c. Potential target outfalls for nearby sediment sampling, RM 3.1 to RM 5.0
Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-06c 6571c Active outfalls.mxd



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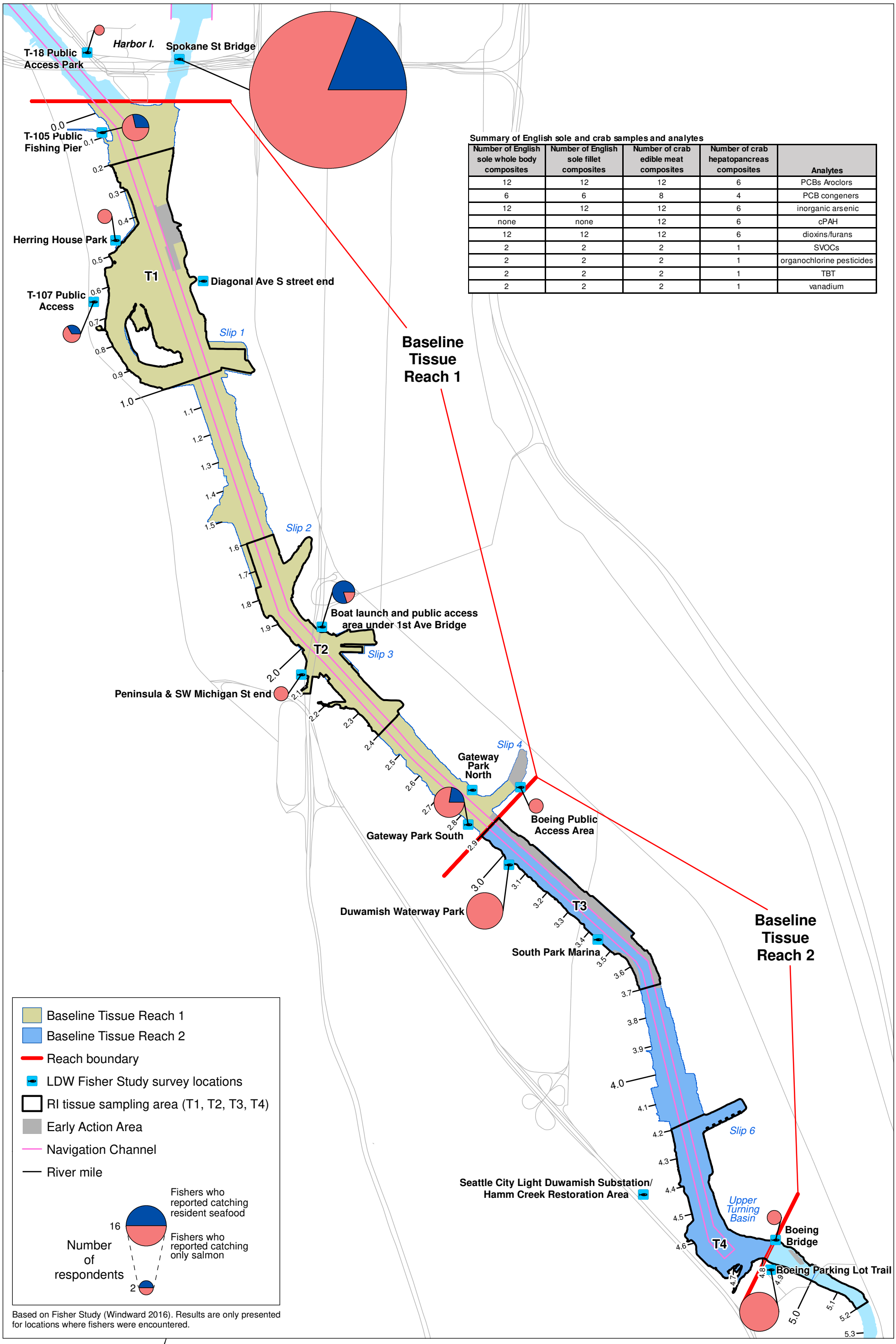
Map 3-7. Bank classifications and existing bank sample locations

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-07 6565 Bank samples and shoreline.mxd



Summary of English sole and crab samples and analytes

Number of English sole whole body composites	Number of English sole fillet composites	Number of crab edible meat composites	Number of crab hepatopancreas composites	Analytes
12	12	12	6	PCBs Aroclors
6	6	8	4	PCB congeners
12	12	12	6	inorganic arsenic
none	none	12	6	cPAH
12	12	12	6	dioxins/furans
2	2	2	1	SVOCs
2	2	2	1	organochlorine pesticides
2	2	2	1	TBT
2	2	2	1	vanadium

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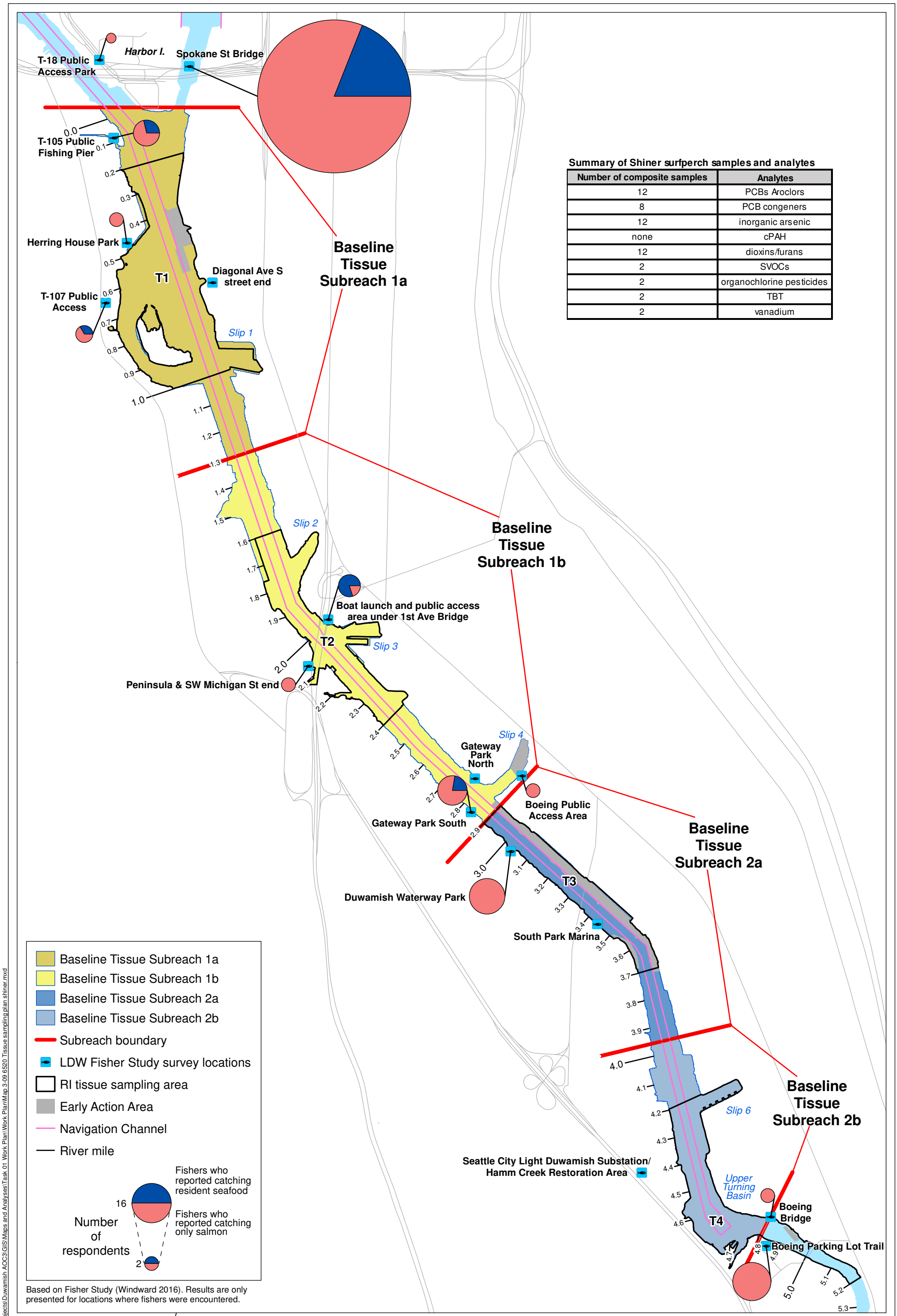
Map 3-8. Conceptual sampling reaches for baseline English sole and crab tissue collection

Prepared by craigh, 8/28/2017. W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-08 6520 Tissue sampling plan crab-sole.mxd



Summary of Shiner surfperch samples and analytes

Number of composite samples	Analytes
12	PCBs Aroclors
8	PCB congeners
12	inorganic arsenic
none	cPAH
12	dioxins/furans
2	SVOCs
2	organochlorine pesticides
2	TBT
2	vanadium

Based on Fisher Study (Windward 2016). Results are only presented for locations where fishers were encountered.

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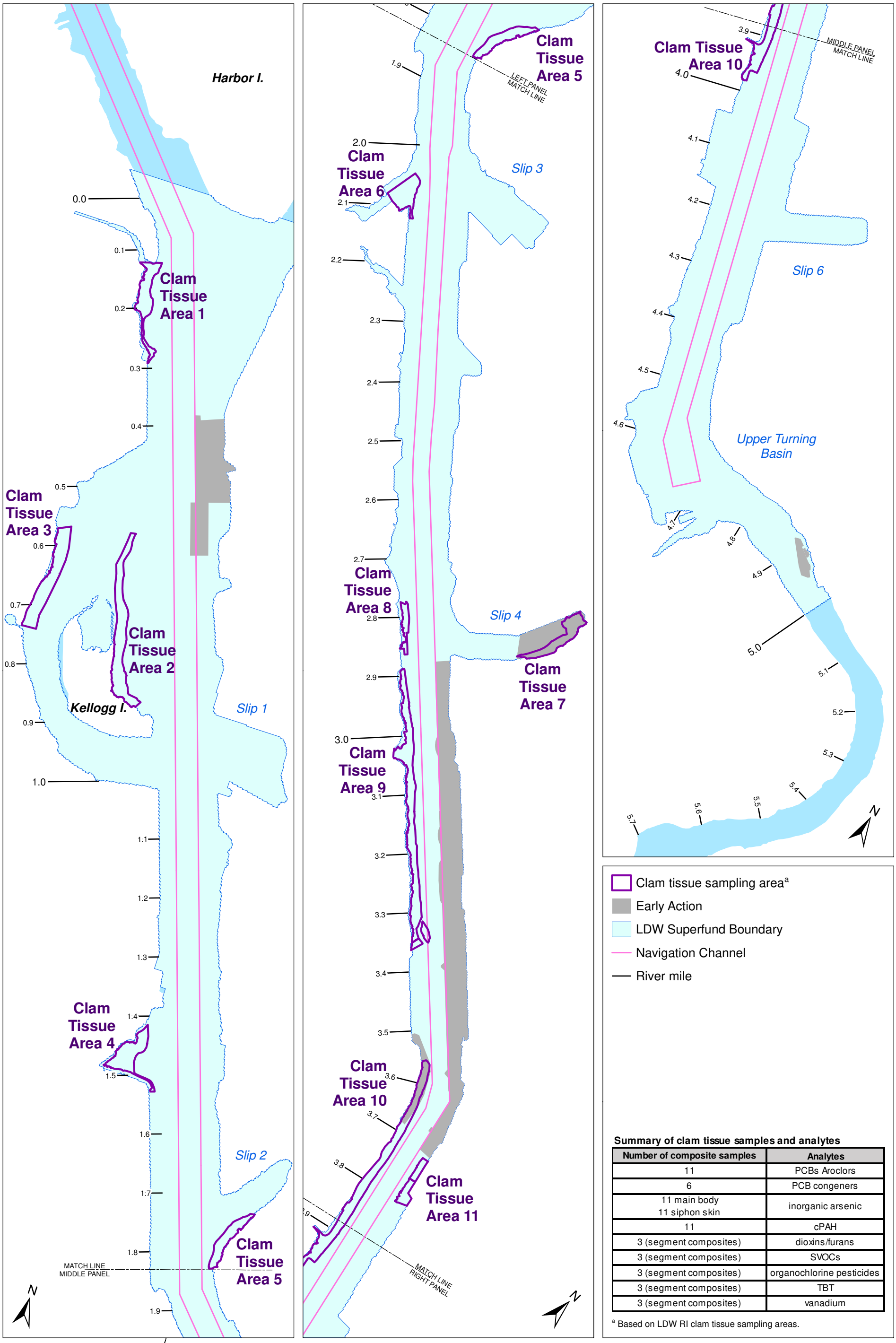
Map 3-9. Conceptual sampling subreaches for baseline shiner surfperch tissue collection

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-09 6520 Tissue sampling plan shiner.mxd



Summary of clam tissue samples and analytes

Number of composite samples	Analytes
11	PCBs Aroclors
6	PCB congeners
11 main body 11 siphon skin	inorganic arsenic
11	cPAH
3 (segment composites)	dioxins/furans
3 (segment composites)	SVOCs
3 (segment composites)	organochlorine pesticides
3 (segment composites)	TBT
3 (segment composites)	vanadium

[a] Based on LDW RI clam tissue sampling areas.

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0 0.1 0.2 Miles

0 0.2 0.4 Kilometers

Scale is the same for each inset map

Map 3-10. Conceptual baseline clam tissue and co-located sediment sampling areas

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map 3-10 6523 Clam sampling plan.mxd

APPENDIX A. STATISTICAL SUPPORT FOR SAMPLING DESIGNS

Table of Contents

Tables

Figures

Maps

Acronyms

95UCL	95% upper confidence limit for the mean
ARAR	applicable or relevant and appropriate requirement
AWQC	ambient water quality criteria
cfs	cubic feet per second
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CLT	Central Limit Theorem
CV	coefficient of variation
DL	detection limit
dw	dry weight
EAA	early action area
ENR	enhanced natural recovery
FS	feasibility study
GOF	goodness-of-fit
LDW	Lower Duwamish Waterway
MDD	minimum detectable difference
MNR	monitored natural recovery
NTR	National Toxics Rule
PCB	polychlorinated biphenyl
PE	polyethylene
ppb	parts per billion
PSS	practical salinity scale
RAO	remedial action objective
RI	remedial investigation

RM	river mile
RME	relative margin of error
ROD	Record of Decision
SD	standard deviation
SE	standard error
SWAC	spatially weighted average concentration
TEQ	toxic equivalent
TSS	total suspended solids
TTL	target tissue level
USGS	US Geological Survey
WAC	Washington Administrative Code
WQC	water quality criteria
ww	wet weight

1 Introduction

This appendix presents information relevant to sampling designs and data analysis of surface sediment (0–10 cm), intertidal sediment (0–45 cm), fish and crab tissue, clam tissue, and surface water.

For each of the sampled media (except surface water), methods to calculate 95% upper confidence limits for the mean (95UCLs), to compare to cleanup levels or target tissue levels (TTLs), are presented. Formulas for each sampled medium are provided based on the current expectation of the statistical distribution for the data. Once collected, each dataset will be evaluated and the most appropriate method for calculating the 95 UCL will be used.

This appendix is organized by media type:

- Section 2 presents statistical evaluation for surface sediment (0–10 cm) sampling design.
- Section 3 presents statistical evaluation for the intertidal sediment (0-45 cm) sampling design
- Section 4 presents statistical evaluation for the fish and crab tissue sampling design
- Section 5 presents statistical evaluation for the clam tissue sampling design.
- Section 6 presents statistical evaluation for the surface water sampling design.
- Section 7 presents the references.

2 Surface Sediment (0–10 cm)

To develop the surface sediment sampling design, data from monitored natural recovery (MNR) areas identified in Record of Decision (ROD) Figure 18[1] (EPA 2014) were used to estimate the magnitude and patterns of variability expected in the Lower Duwamish Waterway (LDW) following active remediation.[2]

The targeted relative margin of error (RME) for the site-wide mean concentration for surface sediments (0–10 cm) in the LDW is ≤ 25%, wherein the RME is calculated as the width of the 95UCL as a percent of the mean. The sampling objective to estimate the site-wide mean with a RME of 25% can be met most cost-effectively through the use of composite samples. Composite samples are not intended to provide information

[1] ROD Figure 18 is titled Selected remedy.

[2] It is acknowledged that baseline sediment chemistry variability will likely be greater than the variability estimated from the MNR dataset, and may be skewed rather than symmetric (i.e., follow a gamma distribution rather than a normal distribution).

regarding the population variance of individual sediment chemical concentrations, nor details of small-scale spatial heterogeneity. That information will be collected through area-specific sampling during remedial design. The baseline surface sediment (0–10 cm) sampling design will provide an efficient estimate of the 95UCL of the site-wide mean to compare to cleanup goals for remedial action objectives (RAOs) 1, 2, and 4.[3]

A spatially balanced sampling design has been developed that includes the collection of a single random sample within *n* (e.g., *n* = 100, 140, 150, or more) grid cells of approximately equal area distributed throughout the LDW. Composite samples with the same number of field samples in each are constructed from groups of *k* neighboring individual samples for analysis. The sample size of analytical samples is *n/k* (e.g., 100 field samples would be used to create 20 composites with 5 samples each). This approach avoids bias and spatial clustering of samples so that the arithmetic mean of the observations is also a spatially weighted average concentration (SWAC), because equal spatial weighting is intrinsic to the sample design.

In future years of site-wide monitoring for RAOs 1, 2, and 4, the number of samples per composite should remain consistent to maintain year-to-year comparability of the datasets. The numbers of field samples and composite samples may change in response to updated information about site variance, and to achieve a desired RME for the site-wide mean. In this way, a robust site-wide 95UCL can be calculated for each sampling event.

The site-wide results for baseline sediment sampling will be used to chart the progression of sediment concentrations toward the cleanup goals. When sufficient sampling events have been completed (e.g., five or more), the trend for these data can be estimated using regression or correlation methods. In the interim, the baseline dataset may be used most simply in a two-sample, one-tailed comparison to a dataset collected in one of the future sampling events. The specific statistical test used will depend on the nature of the datasets (e.g., distribution, equality of variance, number of non-detects). When non-detects are present, Kaplan-Meier estimates of mean and variance will be used, as well as substitution at full detection limit (DL) and at 0 to provide upper and lower bounds for population estimates.

Sections 2.1 through 2.3 of this appendix present analyses using existing data to illustrate the level of variability expected within the LDW following active remediation. These data support a sampling design with 20 composite samples from 140 field samples (5 samples per composite) to achieve the targeted RME of 25% or better during post-remedy sampling, 90% statistical power to detect a 60% decrease in the site-wide

[3] RAO 1 is related to consumption of resident seafood (human health), RAO 4 is related to high-trophic-level ecological risks (river otter), and RAO 2 is related to direct contact (human health) from netfishing (using 0–10-cm sediment samples throughout the LDW) and clamming and beach play (using 0–45-cm sediment sampling in specified areas).

PCB SWAC,[4] and a sampling density within 1.5 times the minimum separation distance, on average. However, after reviewing these results and considering the age and spatial representation of the dataset on which they were based, EPA directed a more conservative assumption regarding variance, which resulted in a sampling design with 24 composite samples of 7 samples each (total of 168 field samples). The EPA-directed sampling design is presented in the Work Plan (Windward and Integral 2017), Section 3.2.1.1.

2.1 SURFACE SEDIMENTS (0–10 CM) DATA USED IN THE ANALYSIS

Surface sediment data from MNR areas (as depicted in ROD Figure 18 and Map A-1 of this appendix) within the RI/feasibility study (FS) dataset were used in this evaluation. Data from MNR areas were selected because they provided the best surrogate for data variability likely to exist following active remediation in the LDW.[5] Results for total PCBs (sum of Aroclors]), carcinogenic polycyclic aromatic hydrocarbon (cPAH) toxic equivalent (TEQ), and arsenic were evaluated.[6]

A summary of the data for each contaminant of concern (COC) by river mile (RM) segment is presented in Table A-1. The three COCs were mostly detected in this dataset (i.e., 88% of the PCB samples had detected concentrations and 95% of the cPAH and arsenic samples had detected concentrations). The data for total PCBs were the most abundant, with sample counts within each segment ranging from 8 to 103 for total PCBs and from 4 to 61 for both cPAH and arsenic. Sample locations within segments were clustered to varying degrees throughout the site; nearest neighbors were less than 50 ft apart in all but one segment for total PCBs, and in all but four segments for cPAH and arsenic.

[4] The feasibility study (FS) estimated a decrease in the site-wide PCB SWAC of approximately 60% between post-EAA conditions (i.e., baseline) and post-remedy conditions (FS Table 9-2).

[5] The only data that were excluded from the MNR area dataset were perimeter samples associated with early action areas (EAAs) (Terminal 117, Slip 4, and Duwamish Diagonal) that were collected prior to remediation and had polychlorinated biphenyl (PCB) concentrations greater than 400 µg/kg dry weight (dw).

[6] The sums of PCB Aroclors and cPAH TEQ were calculated using the LDW RI/FS data management rules. The dioxin/furan data are limited and thus no evaluation has been conducted for dioxin/furan TEQs.

Table A-1. Summary of surface sediment (0–10 cm) data from MNR areas within the RI/FS dataset used to evaluate statistical properties of proposed study designs

RM Segment[a]	Total PCBs (ug/kg, dw)				cPAH TEQ (ug/kg, dw)				Arsenic (mg/kg, dw)			
	Total N	No. NDs	Concentration Range	Min. Distance Between Samples (ft)	Total N	No. NDs	Concentration Range	Min. Distance Between Samples(ft)	Total N	No. NDs	Concentration Range	Min. Distance Between Samples (ft)
0,0.1	16	1	8.4–250	21	14	1	44–720	21	14	0	5.10–21.2	21
0.1,0.3	17	3	3.1–191	1	14	1	9.1–760	1	14	0	3.50–21.9	1
0.3,0.5	16	0	7.0–222	46	13	0	20–530	97	13	1	3.10–17.0	97
0.5,0.6	18	4	0.4–341	1	21	2	4.3–880	1	21	3	3.10–33.9	1
0.6,0.7	16	2	2.6–340	46	11	0	30–480	46	11	0	5.8,0 13.0	46
0.7,0.9	19	1	4–196	58	11	0	34–860	87	11	0	3.10–20.2	87
0.9,1	8	0	51–240	20	4	0	320–660	210	4	0	9.10–31.8	210
1,1.2	16	1	4–302	12	12	0	350–550	62	12	0	9.50–45.0	62
1.2,1.4	13	0	66–290	11	10	0	160–670	11	10	0	8.80–46.8	11
1.4,1.6	17	2	10–340	25	13	0	17–500	25	15	0	1.20–16.7	25
1.6,1.8	30	6	9.5–270	11	22	0	21–520	11	25	0	2.40–26.0	11
1.8,2	16	1	9.5–260	17	13	0	48–890	17	14	0	5.10–17.7	17
2,2.1	13	0	38–296	37	10	0	27–650	49	10	0	4.20–23.1	49
2.1,2.7	32	1	10–204	35	21	2	9.1–1,000	35	26	3	1.80–17.6	35
2.7,2.9	31	0	36–380	13	9	0	34–320	38	9	0	9.00–26.5	38
2.9,3.2	34	2	10–162	6	18	0	32–250	6	18	0	4.90–11.5	6
3.2,3.7	45	5	7.1–380	10	15	0	61– 320	35	18	5	6.50–13.6	35
3.7,4.1	37	4	0.4–370	16	26	0	9.7–210	25	24	0	4.80–14.4	25
4.1,4.6	103	12	3–340	6	61	2	9.4–1400	6	61	0	3.50–17.8	6
4.6,5	48	18	0.3–162	9	36	11	9.4–1060	18	34	3	1.90–51.0	18
Total	545	63			354	19			364	15		

[a] Square brackets are inclusive: [0, 0.1] indicates locations with 0 ≤ RM ≤ 0.1. Left parenthesis indicates strictly greater than: (0.1, 0.3] captures locations with 0.1 < RM ≤ 0.3.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
CV – coefficient of variation
dw – dry weight
MNR – monitored natural recovery
ND – non-detect
PCB – polychlorinated biphenyl
RI/FS – remedial investigation/feasibility study
RM – river mile
TEQ – toxic equivalent

The highly clustered nature of the historical sampling locations (Map A-1 and minimum distance noted in Table A-1) made it inappropriate to calculate simple summaries of the mean and variance of the data within each segment. Instead, a simplified bootstrap estimate[7] of the coefficient of variation (CV) for each of the three COCs indicated that the site-wide CVs for total PCBs and cPAH TEQ were similar, while the CVs for arsenic were slightly lower (Table A-2). Using the highest CVs to inform the study design provides appropriate estimates of the expected RME for the most variable analytes, and a buffer on the expected RME for analytes with lower CVs. Although the CVs for total PCBs and cPAH TEQ were similar, the CV for total PCBs was considered more accurate because there were approximately 200 more total PCB samples than cPAH TEQ samples analyzed throughout the LDW (Table A-1). Consequently, the remainder of the sediment discussion in this appendix presents results from only the total PCBs data; it is assumed that the study design based on PCB data will result in similar or better RME values for the other COCs.

Table A-2. Distribution of the surface sediment CVs across bootstrap replicates

COC	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Total PCBs	0.6	0.8	0.8	0.8	0.8	1.0
cPAH TEQ	0.7	0.8	0.8	0.8	0.9	1.0
Arsenic	0.3	0.5	0.5	0.5	0.6	0.7

Note: Each bootstrap replicate (B = 1,000) was comprised of 100 observations randomly selected from the RI surface sediment dataset (Map A-1), with the stipulation that all sampling locations were separated by at least 200 ft.

COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CV – coefficient of variation
PCB – polychlorinated biphenyl
RI – remedial investigation
TEQ – toxic equivalent

2.2 SURFACE SEDIMENTS (0–10 CM) METHODS

The sampling programs represented in the RI/FS dataset used a variety of sampling designs with different objectives, and many of the sampling programs focused on smaller areas. As a result, the RI/FS dataset has irregular sampling densities across the site, including some areas with very tightly clustered samples and other areas with very few samples (Table A-1, Map A-1). Using spatially clustered samples as if they were independent samples would likely result in biased estimates of mean and variance, which would not be representative of the expected site-wide conditions following active remediation.

Sampling variance is the variability of summary statistics (e.g., the mean) if the same sampling design, with the same sample size, were applied to the same population

[7] Each bootstrap replicate (B = 1,000) drew a random sample of 100 observations without replacement from the RI dataset, with the stipulation that sampling locations were separated by at least 200 ft.

multiple times. A lower sampling variance results in improved precision in estimates of summary statistics. Some ways to reduce sampling variance include:

- Reducing variance among samples (e.g., by analyzing composites of multiple grab samples, thereby averaging over smaller scale variability)
- Increasing sample size throughout the site (e.g., a mean of 100 samples has lower variance than a mean of 20 samples)
- Using a stratified sampling design (e.g., by having higher sample densities within areas [strata] with higher variance or different means to reduce the sampling variability in the overall mean)

To use the existing data from MNR areas (Map A-1) to assess the benefits of different sampling approaches and determine which could be most efficiently used to improve precision, three key questions were asked. These questions, and the methods used to answer them, are described below.

2.2.1 Question 1

What minimum separation distance between samples would be required to produce spatially independent data?

The minimum separation distance between samples was required to reduce the bias and redundancy of information resulting from the tightly clustered samples within the RI dataset. The minimum separation distance was used to restrict how the data within the RI dataset were sampled in the bootstrapping exercise.

Method: A correlogram displays the average spatial correlation (Moran's I) between pairs of samples within increasing distance intervals. The distance interval at which the correlation becomes nominal was used to determine the minimum separation distance. Correlograms were created using two different functions in R (R Core Team 2016): *correlog{pgirmess}* (Giraudoux 2016) and *correlog{ncf}* (Bjornstad 2016).

2.2.2 Question 2

What is the variance of concentrations within different reaches of the LDW, and is it approximately consistent throughout the LDW?

If the spatial variance were very different within different sections of the river, this would indicate that variance strata exist and precision of the site-wide mean could be improved by stratifying the river and taking more samples where variance is higher.

Method: Random groups of five adjacent samples were bootstrapped from the RI dataset. A sample size of five was chosen to mimic the sample sizes that will be used in composite sampling, and 5,000 bootstrap samples were drawn. Within each group, the randomly selected samples were separated by the minimum distance established by the answer to Question 1, and no more than a maximum distance of 1,320 ft (0.25 mi). This maximum separation distance was used because it was large enough to not limit the

number of bootstrapped sample groups that could be formed, but not so large as to average over spatial patterns in concentrations that were present in this dataset. The variability within these groups of five samples was plotted against location along the river (average river mile of the five samples within the group). Any large changes in the magnitude of variance at different river miles would support the use of a stratified sampling design.

2.2.3 Question 3

What is the expected sampling variance for the LDW-wide mean using a set of 100 spatially balanced random samples combined into 20 composite samples?

Method: Simulations of 20 independent composites, each containing 5 subsamples, were bootstrapped from the existing data to estimate variance in the mean of 20 composite samples. If the answer to Question No. 2 indicated that variance strata exist, sampling would be specified within these strata. Otherwise, sampling would occur throughout the river without specification of separate strata. The specific steps in the bootstrap approach for a non-stratified design are detailed below.

1. Divide the 5 mi of the LDW into 20 segments of approximately equal area.[8]
2. Subsample within each segment to collect five samples separated by a minimum distance (i.e., the answer to Question 1).
    a. Record the mean for these five samples as the composite sample estimate; treatment of non-detects used substitution at one-half the DL.[9]
    b. Record the standard deviation (SD) for these five samples as the within-composite SD (note: this would not be observed in the baseline sampling, because all individual samples would not be analyzed, although they would be archived).
    c. Record the minimum, maximum, and average distances between samples to verify bootstrap methods.

[8] These segments were different than the conceptual composite areas proposed for the baseline sampling (Map 3-2 of the main document). The areas on Map 3-2 may not have had enough data points in this dataset to support the bootstrap subsampling (e.g., none of the EAAs were represented in this dataset). The segment boundaries used for this bootstrapping constrained the number of samples available for each random draw (Table A-1). These boundaries were chosen to capture enough data points distributed throughout each segment to ensure that the full range of concentrations within the segment would be represented across the bootstrap replicates. Different segment boundaries could yield slightly different results for any one sample, but the distribution and density of data points in this dataset were large enough that large differences in the overall sampling variance are not expected.

[9] Preliminary simulations compared results between substitution using full and one-half DL to estimate the mean. Due to the high detection frequency, the method used to treat non-detects had very little effect on the outcome.

3. Repeat Step 2 within each of the 20 segments.
4. Store the 20 simulated composites as a single bootstrap replicate of the LDW-wide sample.
    a. Record the mean, SD, skewness, and kurtosis for the bootstrap sample.
    b. Test the goodness-of-fit (GOF) of the bootstrap sample to a normal distribution (Shapiro-Wilk's test), and record the p-value. Non-rejection of the normality test justifies the use of the *t*-interval to estimate the 95UCL for the site-wide mean; otherwise, a 95UCL for a gamma-distributed dataset would be appropriate.
5. Repeat Steps 2 through 4 many times (B = 10,000) to develop a distribution of expected mean and sampling variance.

Section 2.3 presents the results from the analyses described above to answer the preceding questions. The outcome of the GOF test and estimate of the CV for each bootstrap replicate (Step 4) were used to estimate the RME for the mean from a sample design that utilized a spatially balanced collection of 20 composite samples (Section 2.5).

2.3 SURFACE SEDIMENTS (0–10 CM) RESULTS

The simulation results presented in this section are based on a preliminary sampling design of 5 independent samples composited (i.e., averaged) within each of 20 non-overlapping river segments of approximately equal area. The implications of increasing sampling density to increase the number of field samples per composite, the number of analytical composites, or both, are discussed in Section 2.5 where the final sampling design is described.

2.3.1 Question 1

The correlogram for total PCBs in sediments (Figure A-1) suggests that the spatial correlation is strongest within approximately the first 200 ft, and that some residual spatial correlation exists at up to 400 ft. Beyond 400 ft, the correlation is consistently low (less than 0.20) and within the noise of the random correlations present at greater distances. Since it appears that samples within 200 ft are, in general, too highly correlated to be considered spatially independent, a minimum separation distance of 200 ft is used for the bootstrap sampling in the subsequent evaluations reported in this appendix. A larger separation may be warranted to ensure independence, but the level of clustering in this dataset is such that using a larger minimum separation distance would severely limit how the sample values could be combined in the simulations.

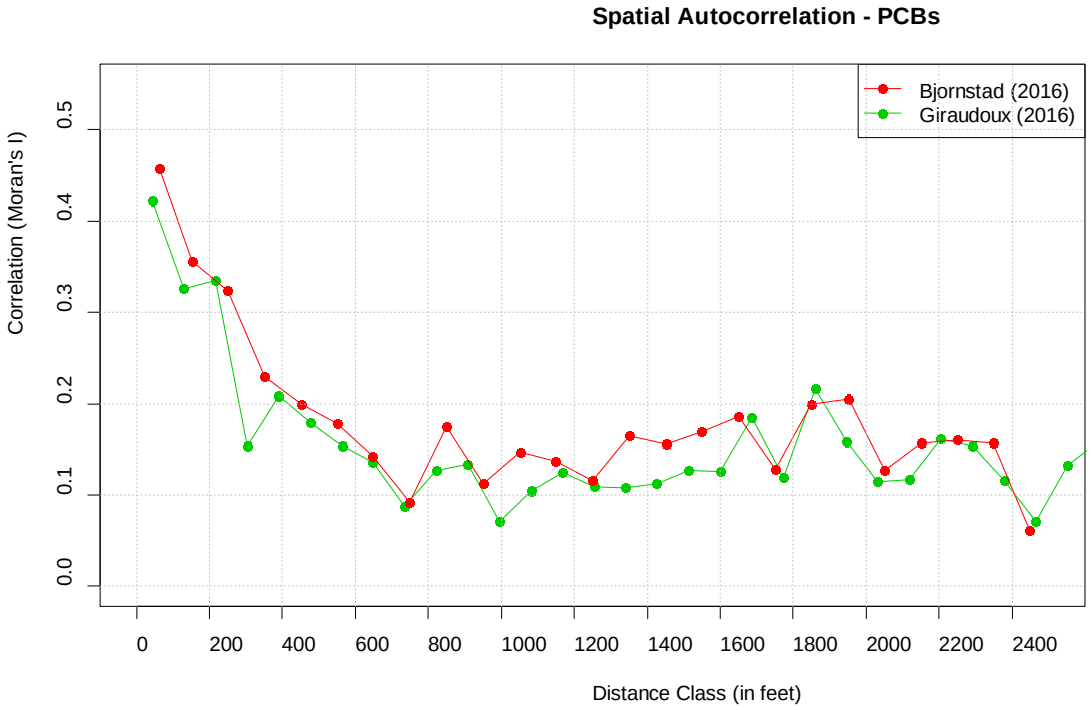


Figure A-1. Correlogram (Moran's I versus distance) for total PCBs in the RI dataset

2.3.2 Question 2

The SDs within bootstrapped groups of five samples that were separated by distances between 200 and 1,320 ft (B = 5,000) were plotted against river mile (Figure A-2). These results provided a measure of mid-range (200 ft to 0.25 mi)[10] spatial variability across the LDW. This investigation addressed the question of whether variance strata exist within the site. The magnitude of the SDs within sample groups of 5 was fairly consistent throughout the length of the river (Figure A-2). A few exceptions included the areas below RM 0.5 and between RM 2.0 and RM 2.6. These areas with lower variance tended to have fewer samples, so it was assumed that the full variance in these areas was not sampled. These results indicate that dominant variance strata are absent and the entire river can be sampled with the same density throughout.

[10] The approximate scale of separation present among individual samples contributing to a single composite sample in the proposed study design.

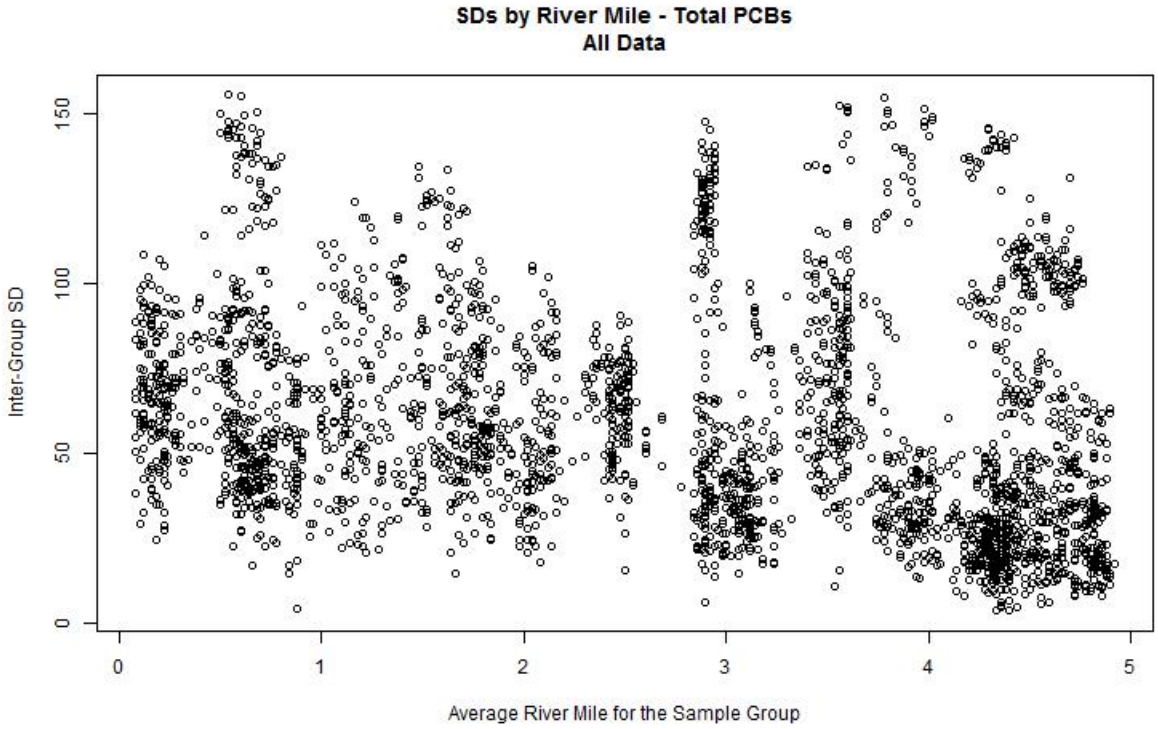
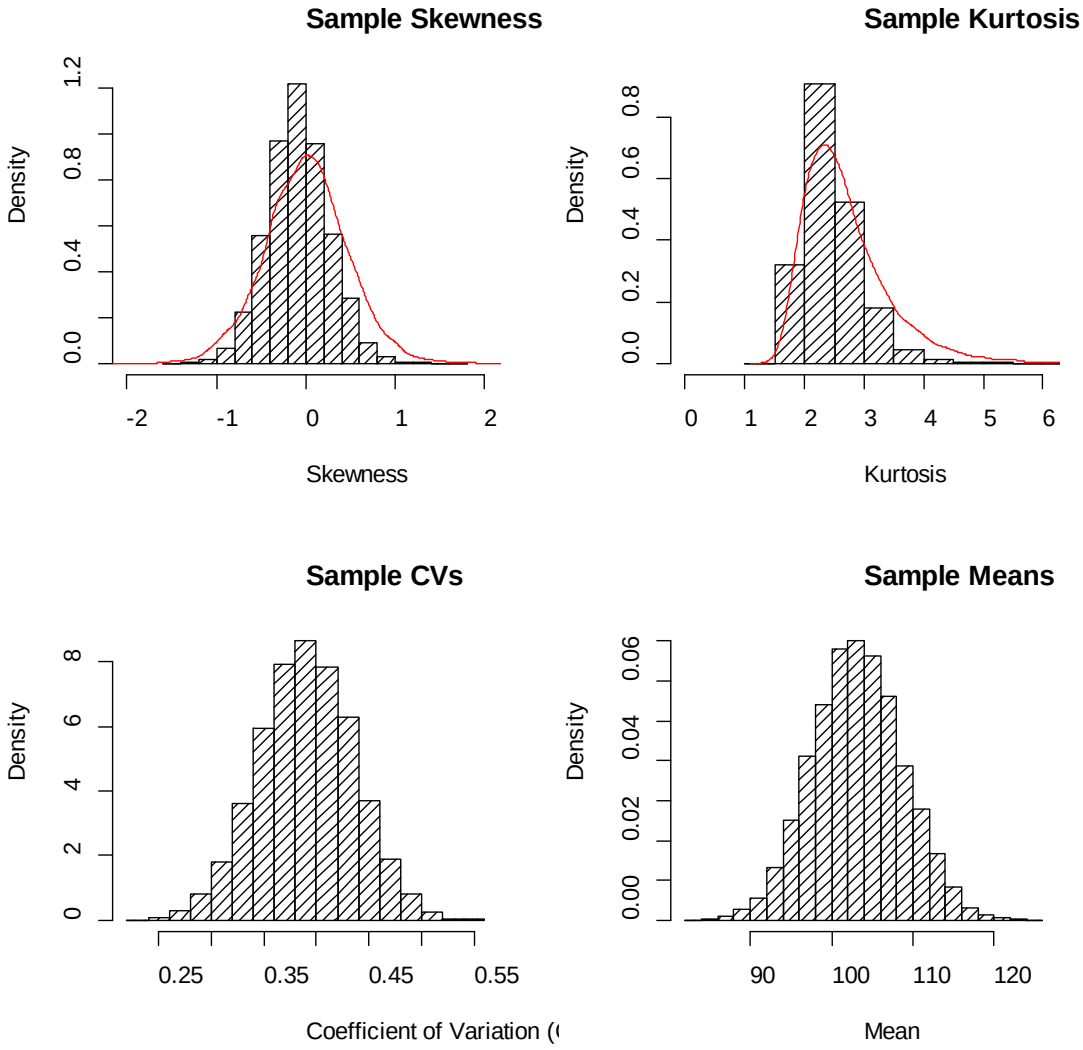


Figure A-2. Inter-group SDs for bootstrap sample groups within 200 and 1,320 ft, plotted against the average river mile

2.3.3 Question 3

Because no strata were identified (via Question 2), LDW-wide bootstrap sampling was conducted using a non-stratified design. The frequency distributions of skewness and kurtosis for each of the bootstrapped samples (size 20) indicated that these samples were similar to simulated normal samples of the same size (Figure A-3). The bootstrapped samples were generally symmetric (skewness values near 0, Table A-3) with a tendency for flatter distributions (kurtosis values less than 3) and a low probability of outliers (few kurtosis values greater than 4, Table A-3). The sampling distribution of the mean (Figure A-3) is strongly Gaussian, an expected result based on the Central Limit Theorem (CLT).[11]

[11] The CLT establishes that the mean of a sample randomly drawn (from any distribution) will approach normality as sample size increases.



Sample size of 20 within each bootstrap replicate, B = 10,000. The red line overlaid on the skewness and kurtosis histograms shows values for simulations of normally distributed samples of size 20.

Figure A-3. Frequency distributions of summary statistics (skewness, kurtosis, coefficient of variation, and mean) from each LDW-wide bootstrap replicate

Table A-3. Distribution of skewness, kurtosis, and CV for samples of size 20, across 10,000 bootstrap replicates

	Minimum	1st Quartile	Median	Mean	3rd Quartile	95th Percentile	Maximum
Skewness	-1.4	-0.3	-0.1	-0.1	0.1	0.5	1.7
Kurtosis	1.4	2.1	2.4	2.4	2.7	3.3	6.3
CV	0.23	0.36	0.39	0.39	0.42	0.46	0.55

CV – coefficient of variation

The distribution of the 20 composites within each bootstrap replicate was rejected as normally distributed (Shapiro-Wilks $p < 0.05$) in less than 2% of the bootstrap replicates. This is less than the 5% expected by chance, so these results support the expectation that a set of 20 spatially balanced composite samples from the post-remediated LDW will be a normally distributed sample.

The distribution of sample CVs had an average of 0.4, a 95th percentile of 0.46, and a maximum value of 0.55 across the 10,000 bootstrap replicates (Figure A-3, Table A-3). The average and maximum CVs from this distribution were used in the sample size estimation presented in Section 2.5.

2.4 SURFACE SEDIMENTS (0–10 CM) 95 UCL

Supported by the results in Section 2.3 and the CLT, the sampling distribution of the mean (n = 20 composite samples) is expected to be normally distributed. The *t*-interval can be used to calculate the 95UCL of the site-wide mean of a single population as:

$$95UCL = \bar{X} + t_{(0.05,n-1)} \frac{SD(X)}{\sqrt{n}} \qquad \textbf{Equation 1}$$

Where:

$\bar{X}$ is the average of the *n* samples

$SD(X)$ is the standard deviation of the *n* samples

$t_{(0.05,n-1)}$ is the critical value from the t-distribution with 5% in the upper tail, and *n*-1 degrees of freedom

2.5 SURFACE SEDIMENTS (0-10 CM) DISCUSSION

The sampling design for surface sediment (0–10 cm) is intended to meet the RME target of 25% for the site-wide mean.

The distribution of the mean of 100 samples drawn from the same population is expected to be approximately normal based on the CLT and the law of large numbers. When the 100 samples are combined into 20 averages (composites), the distribution of the mean is still expected to approach normality through the CLT. The bootstrap estimates from existing data that were used to simulate the post-remediated LDW

concentration distributions illustrated that the sampling distribution of the mean was indeed Gaussian (Figure A-3). In addition, the 20 composite samples generated in each bootstrap replicate were consistently normally distributed (Section 2.3.3).

The simulations presented in this appendix used existing RI data from the MNR areas. This dataset does not include data from any areas slated for active remedies (i.e., dredging, capping, or enhanced natural recovery [ENR]). So while the MNR dataset used for these simulations is expected to approximate or overestimate the variability post-remediation, it is likely to underestimate the population variance that may be seen during the baseline sampling period. Increasing the sampling density would capture more of this population variability during baseline sampling. The simulations are expected to overestimate the population variance following implementation of the remedy, which will reduce variance in sediment concentrations throughout the LDW since clean sand will be the post-remediation surface in all active remedy areas.

For the stratified random sampling design,[12] the sampling density can be expressed as the range of distances between nearest neighbors. For 100 to 170 grid cells of approximately equal area, the nearest neighbor distances between grid cell centroids were estimated (Table A-4). A desirable sampling density would place samples within 1.5 times the minimum autocorrelation distance, on average. For a minimum autocorrelation distance of 200 ft, 100 grid cells produce a sampling density that averages 1.9 times the minimum separation distance, and ranges from 1 to 3.6 times that distance. For areas with more spatial heterogeneity in the concentrations, this sampling density may be too coarse to capture the variability of concentrations present during baseline sampling. With 140 grid cells, the sampling density increases to an average of 1.4 times the minimum separation distance, and has an approximate range of 1 to 2.6 times that distance. Estimated results for 150, 160, and 170 grid cells are also shown in Table A-4. Based on sampling density considerations, 140 grid cells provide the most cost-effective design for achieving the approximate distance separation targets (within 1.5 times as the minimum separation distance, on average). Note that the actual values may be slightly different from the approximated distance values shown in Table A-4.

Table A-4. Approximate distance between centroids of adjacent grid cells for five different sampling densities

Number of Grid Cells	Minimum Distance (ft)	Maximum Distance (ft)	Mean Distance (ft)	Mean Area per Sample (ac)
100[a]	232 (~1x)[b]	726 (~3.6x)	375 (~1.9x)	4.41
140	200 (~1x)	520 (~2.6x)	270 (~1.4x)	3.2
150	200 (~1x)	480 (~2.4x)	250 (~1.3x)	2.9

[12] Each grid cell is a stratum with a single random sample.

Number of Grid Cells	Minimum Distance (ft)	Maximum Distance (ft)	Mean Distance (ft)	Mean Area per Sample (ac)
160	200 (~1x)	450 (~2.3x)	230 (~1.2x)	2.8
170	200 (~1x)	430 (~2.1x)	220 (~1.1x)	2.6

[a] Results for 100 grid cells were calculated based on the preliminary design. Subsequent results in this table were scaled up proportionally and rounded to two significant figures. The shape of the LDW restricts how the grid cells may be arranged to accommodate a target sampling density, so these values are approximations.

[b] Value in parenthesis is the multiplier of the approximate autocorrelation distance of 200 ft that achieves the separation distance shown.

LDW – Lower Duwamish Waterway

A sampling density of 140 grid cells combined into 20 composite samples of 7 samples each was proposed for baseline sampling. This plan provides a sampling interval that randomly varies between 200 and approximately 500 ft, and within approximately 270 ft on average (Table A-4). It avoids severe autocorrelation among the samples (at < 200 ft separation) while capturing the smaller-scale heterogeneity (< approximately 500 ft) for inclusion in each composite sample. Each of the 20 composite samples represents, on average, approximately 22 ac of the site (each with 7 samples). The expected post-remedy RME for the mean using this approach is 18%. Simulations for a sampling approach with 20 composite samples of 7 samples each suggest a lower CV and comparable precision compared to designs using 20 composites of 5 samples each, or 34 composites of 7 samples each (Table A-5).

Table A-5. CV results for simulated datasets under three different sampling approaches

Total No. Field Samples	No. of Composites	No. of Field Samples per Composite	Median CV	Maximum CV	% with Normality Rejected	% RME Using Maximum CV[a]
100	20	5	0.38	0.53	2%	20%
140	20	7	0.34	0.46	2%	18%
170	34	5	0.45	0.55	7%	17%[b]

[a] RME calculated using Equation 2.

[b] Uses n = 30.

CV – coefficient of variation

RME – relative margin of error

Simulations similar to those detailed in Section 2.2 were conducted to evaluate how the distribution of composite samples would be affected if a greater sampling density was used and the area for each composite sample was reduced. Simulated composite samples from 34 segments,[13] with 5 samples in each composite, resulted in a

[13] The simulation was performed with 34 segments and 170 field samples, because it would have been much more time consuming to assess 30 samples of equal area due of the nature of the dataset. This simulation is provided to illustrate the effect of quantifying spatial variability using a larger number of composites.

distribution with greater relative variability than that of the distribution observed for 20 composites of 5 or 7 samples each (CVs shown in Table A-5). The higher normality rejection rate also indicated the greater tendency for higher skewness in a simulated dataset of 34 samples over that of 20 samples. This skewness is presumably due to more localized conditions being represented by each of the 34 composite samples. The skewness of composite samples from smaller sampling areas would be even more pronounced during baseline sampling, when concentrations in active remedy areas remain elevated, potentially resulting in a more uncertain estimate of the site-wide 95UCL.

The simulation results reported in Section 2.3.3 and Table A-5 support the use of a normal *t*-interval to calculate the 95UCL for the site-wide mean (Equation 1) for 20 composite samples of 5 or 7 samples each. When the data are available and ready to be evaluated, the most appropriate methods to calculate the 95UCL will be determined based on graphical evaluations and GOF tests. For this *a priori* estimation, the 95UCL for the site-wide mean may be expected to be calculated using Equation 1; thus, the RME is calculated using the following equation (with n = 20):

$$\%RME = CV \times \frac{t_{(0.05,n-1)}}{\sqrt{n}} \times 100 \qquad \textbf{Equation 2}$$

For CVs ranging from 0.4 to 0.6 (values rounded up from the median and maximum CVs observed in the bootstrap results, Table A-5), the sampling design of 140 spatially balanced samples, combined into 20 composites of 7 samples each, is expected to achieve the targeted 25% RME for the post-remediated site-wide mean (i.e., 15 to 23%, respectively).

It is important to point out that these results are dependent on the data used for the simulations. EPA has expressed concern that these data may underestimate the variability in PCB concentrations in surface sediment during baseline sampling. The dataset includes only data from MNR areas, which represent approximately 57% of the total LDW (235 of the 412 ac at the site). These areas are away from upland cleanup sites and have lower sediment concentrations suggesting they are not subject the same historical or ongoing sources as areas of the river with higher PCB concentrations, and as such represent the best surrogate available for general ambient variability in the LDW after the cleanup.

Because the MNR dataset excludes data from the active remedy areas (43% of the LDW), it is likely to underestimate the variability expected during baseline sampling (when active remedy areas other than the EAAs still have elevated concentrations). In contrast, however, the MNR dataset is likely to overestimate variability post-remedy, when all active remedy areas have been cleaned up and concentrations are lower. Since the main purpose of this assessment is to estimate variability for long-term monitoring, the sampling design of 20 composite samples with 7 samples each (for a total of 140 samples) was based on ambient variability expected post-remedy, rather than current (baseline) conditions. This design optimized the balance between power, error, and

autocorrelation. However, in addition to being focused on the post-remedy condition, it was based on an older dataset that was limited in certain areas, so EPA directed an approach with 24 composite samples with 7 samples each (for a total of 168 samples).

3 Intertidal Sediments (0–45 cm) for Direct Contact During Beach Play and Clamming Scenarios

The intertidal surface sediment (0–45 cm) sampling effort is designed to estimate the 95UCL concentrations for the LDW-wide clamming areas, and the 95UCL concentration for each of the eight beaches. These 95UCL concentrations of human health risk drivers will be used to evaluate cleanup-level compliance for direct contact associated with clamming and beach play RAOs.

Using the compositing plan outlined in Section 3.2.1.4 of the Work Plan (Windward and Integral 2017), the three composite samples will be effectively field replicates of the mean from the sampled locations, either by beach or across all clamming areas. The variance among these composite samples will represent small-scale spatial variability as well as sampling and analytical error, and will be used to calculate 95UCLs at the scale dictated in the ROD.

3.1 Intertidal Sediments (0–45 cm) for Direct Contact During Beach Play 95UCL

Three composite samples (each composite comprised of three, five, six, or nine field samples, depending on beach size) will be available from each beach to estimate the 95UCL for that beach. The shape of the distribution cannot be properly evaluated with only three samples; this level of compositing may be inadequate to invoke the CLT without more information regarding the underlying distributions. Prior to using a 95UCL that assumes a normal distribution, the distribution of concentrations within each beach will be investigated based on available data for that beach.[14] The existing data, along with any conclusions that may be reached regarding the apparent distributional form of individual grab samples for each beach, will be presented in the data evaluation report.[15] If individual grab samples from an individual beach do not show significant skewness (i.e., D'Agostino's test has a two-tailed p-value greater than 0.05), then a 95UCL for the baseline composite samples from that beach will be calculated using a *t*-interval. For beaches with insufficient previous data or where significant skewness was found, a non-parametric Chebyshev interval will be used. The

[14] Existing datasets used in this analysis will be screened to match as closely as possible the sampling and analytical methods used in the baseline sampling; specifically, they must include samples collected from multiple locations across an individual beach to provide information about beach-wide variability.

[15] Methods to evaluate the underlying distributional characteristics will include graphical QQ-plots to look for outliers. Any identified outliers will be scrutinized prior to inclusion in D'Agostino's hypothesis test for skewness (using a two-tailed $\alpha = 0.05$).

Chebyshev's inequality may result in conservatively high 95UCLs. This baseline sampling effort will provide an approximate value for the mean at each beach; beach-specific UCLs following the remedy will have a smaller RME as skewness decreases. Future sampling to verify compliance with the cleanup levels may be required with increased sampling density to develop a 95UCL based on a normally distributed dataset.

Using this approach, the 95UCL will be derived for each beach using either the standard equation for a normally distributed population with small sample sizes (Equation 1), or Chebyshev's inequality (Equation 3) with n = 3, and $\bar{X}$ and SD(X) as the mean and SD, respectively, of the three samples from each beach.

A non-parametric 95UCL for any distribution is provided by Chebyshev's inequality:

$$95UCL = \bar{X} + \sqrt{\left(1/0.05 - 1\right)} \times SE \qquad \textbf{Equation 3}$$

3.2 Intertidal Sediments (0–45 cm) for Direct Contact During Clamming 95UCL

Three composites samples, each representing the site-wide average, will be used to estimate the 95UCL of the site-wide mean. The shape of the distribution cannot be evaluated with only three samples, but these samples (each a composite of 71 field samples) will represent field replicates of the clamming area-wide mean, so the CLT may be invoked and normality assumed. Based on this assumption, the 95UCL will be derived with the standard equation for a normally distributed population (Equation 1) with n = 3, and $\bar{X}$ and SD(X) as the mean and SD, respectively, of the three samples across the site.

4 Fish and Crab Tissue

The fish and crab tissue sampling effort is designed to estimate the LDW-wide 95UCL concentrations for comparison to TTLs related to RAO 1 (ROD Table 21[16] (EPA 2014)). The targeted RME for the site-wide mean concentration for fish and crab tissues in the LDW is ≤ 25%, wherein the RME is calculated as the -width of the LDW-wide 95UCL as a percent of the mean.

To develop the fish and crab tissue sampling design, past data from several LDW tissue sampling efforts (primarily the 2007 RI/FS dataset with additional information for Dungeness crab provided by sample results from 2004 and 2005 (Windward 2010a)) were evaluated. Distributional characteristics of the individual tissue concentrations and site-wide patterns in the mean concentrations were used to identify the best statistical model to identify the sample sizes expected to achieve the targeted RME.

[16] ROD Table 21 is titled *LDW resident fish and shellfish target tissue concentrations.*

The recommended design includes dividing the LDW into two reaches with four subreaches and creating composite samples of each tissue type within each reach. The reach designations are based on concentration patterns observed in previous tissue data and, where fishing occurs for resident species, per the fishers study (Windward 2016).

Similar to how baseline sediment data will be used in the future, the site-wide results for baseline tissue sampling will be used to chart, by species, the progression of site-wide tissue concentrations toward the cleanup goals. When sufficient sampling events have been completed (e.g., five or more), the trend for these data can be estimated using regression or correlation methods. In the interim, the baseline dataset may be used most simply in a two-sample, one-tailed comparison to a dataset collected in one of the future sampling events. The data should be collected in the same manner over time (i.e., same number of individuals per composite and all same sampling methods) for an "apples to apples" comparison. The specific statistical test used will depend on the nature of the datasets (e.g., data distribution, equality of variances, number of non-detects) and be appropriate for the stratified sampling design.

4.1 FISH AND CRAB TISSUES DATA USED IN THE ANALYSIS

The 2007 RI fish and crab tissue data were used to assess variability among composites for the tissue types and species targeted in the baseline sampling (Table A-6). Data from 2007 were primarily used because earlier data were temporarily elevated following dredging in both the LDW (e.g., Duwamish / Diagonal early action event) and East Waterway. Because of the paucity of information for Dungeness crab in the 2007 dataset, results from 2004 and 2005 (Windward 2010a) were used to provide additional information regarding variance.

In 2007, composite samples were collected within four reaches, with RI reaches T1 and T2 contained within baseline Reach 1 (RM 0.0 to RM 2.9) and RI reaches T3 and T4 contained within baseline Reach 2 (RM 2.9 to RM 5.0). Samples from the different reaches had different mean concentrations, so data from within the RI reaches were appropriately combined using a stratified model to estimate the variability of the site-wide mean for the proposed baseline survey (Table A-6). When there are location effects within the population, a stratified model will produce a smaller standard error and hence, a smaller RME. The formulas used to calculate a stratified mean and SD are provided in Section 4.4. Table A-6 provides site-wide estimates of the mean and SD for each tissue type for both stratified models and single stratum models that would be appropriate if there were no differences in mean concentrations among the reaches.

The risk drivers for fish and crab tissues are PCBs and dioxins / furans. In this appendix, results for total PCBs (sum of Aroclors) are the only data evaluated for fish and crab tissues, because the dataset for total PCBs is more robust than the datasets for dioxins / furans.

Table A-6. Summary statistics for the 2007 fish and crab tissue total PCB results, including the mean, SD, and CV

Baseline Reach	RI Reach	Tissue Type	N[a]	Mean Concentration (µg/kg, ww)	SD	CV	Comment
Dungeness crab							
1	T1	edible meat	1	15	na	na	4 individuals in this sample
	T1	whole body (calc'd)	1	97	na	na	4 individuals in this sample
	T2		0	na	na	na	no Dungeness caught in this reach
2	T3	edible meat	3	43	6.7	15%	
	T3	whole body (calc'd)	3	234	103	44%	footnote c
	T4		0	na	na	na	no Dungeness caught in this reach
Site wide – single stratum mean and SD		edible meat	4	36	15	42%	
		whole body (calc'd)	4	200	108	54%	
Site wide – stratified mean and SD		edible meat	4	29	6.7	23%	used SD from T3 for each reach
		whole body (calc'd)	4	166	103	62%	used SD from T3 for each reach[c]
		whole body (calc'd)	3	136	21	15%	used SD from T3 with outlier excluded
English sole							
1	T1	fillet with skin	3	343	138	40%	
	T1	whole body	6	525	178	34%	
	T2	fillet with skin	3	293	107	36%	
	T2	whole body	6	693	219	32%	
2	T3	fillet with skin	3	403	78	19%	
	T3	whole body	6	893	364	41%	footnote b
	T4	fillet with skin	0	na	na	na	
	T4	whole body	1	300	na	na	
Site wide – single stratum mean and SD		fillet with skin	9	347	106	31%	
		whole body	19	683	300	44%	
Site wide – stratified mean and SD		fillet with skin	9	361	110	31%	used residual standard error as SD for each reach
		whole body	19	709	266	38%	used residual standard error as SD for each reach
Shiner surfperch							
1a	T1	whole body	6	268	59	22%	
1b	T2	whole body	6	415	115	28%	

Baseline Reach	RI Reach	Tissue Type	N[a]	Mean Concentration (µg/kg, ww)	SD	CV	Comment
2a	T3	whole body	6	763	314	41%	footnote b
2b	T4	whole body	4	315	66	21%	
Site wide – single stratum mean and SD		whole body	22	452	263	58%	
Site wide – stratified mean and SD		whole body	22	440	181	41%	used residual standard error as SD for each reach

Note: Results shaded in blue are the appropriate site-wide estimates for the stratified sampling design that is used in power and sample size calculations.

[a] N = number of composite samples. The numbers of individuals per composite were: 5 individuals (Dungeness crab and English sole) and 10 individuals (shiner surfperch), unless otherwise noted.

[b] High variance was influenced by a single value. Without that value, the CV was greatly reduced, supporting increasing the number of fish per composite in baseline sampling, where feasible.

[c] High variance reported herein was influenced by a single hepatopancreas sample (individual values were 420, 520, and 1020 µg/kg ww). This elevated result is suspect, since this level of variability was not observed in the Dungeness crab composites from 2004 and 2005 datasets. Without that value, the mean and SD were 175 and 21, respectively (CV of 12%).

CV – coefficient of variation
PCB- polychlorinated biphenyl
SD – standard deviation
na – not applicable
RI – remedial investigation
ww – wet weight

4.2 FISH AND CRAB TISSUES METHODS

In the baseline sampling to be conducted, English sole and Dungeness crab specimens will be collected and composited within each of two reaches of the LDW: Reach 1 (RM 0.0 to RM 2.9) and Reach 2 (RM 2.9 to RM 5.0) (Map 3-8 of the main document). Shiner surfperch specimens will be collected and composited within each of four subreaches, each comprising one-fourth of the LDW: subreach 1a (RM 0.0 to RM 1.25), subreach 1b (RM 1.25 to RM 2.9), subreach 2a (RM 2.9 to RM 3.75), and subreach 2b (RM 3.75 to RM 5.0) (Map 3-9 of the main document). Four subreaches are being sampled for shiners instead of two because tissue data collected as part of the RI (Windward 2010a) indicated that PCB concentrations and PCB congener patterns showed more spatial differentiation for shiner surfperch than for other fish and crab species analyzed in the RI.

In the 2007 RI/FS dataset, differences in mean concentrations were observed among the reaches (Table A-6 and Figure A-4). Consequently, a stratified model was the most appropriate model to estimate the site-wide mean and sampling variance for fish and crab tissues, with each reach or subreach having equal weight. A stratified model was applied to the data from the 2007 RI dataset, and means, SDs, and residuals from the stratified model were used to estimate site-wide CVs and examine distributional characteristics of the data (e.g., approximately normal or gamma distributed). Summary statistics (mean, SD, and CV) are summarized in Table A-6 by reach, and site-wide estimates are presented for both a stratified model and using a pooled (single stratum) estimate.

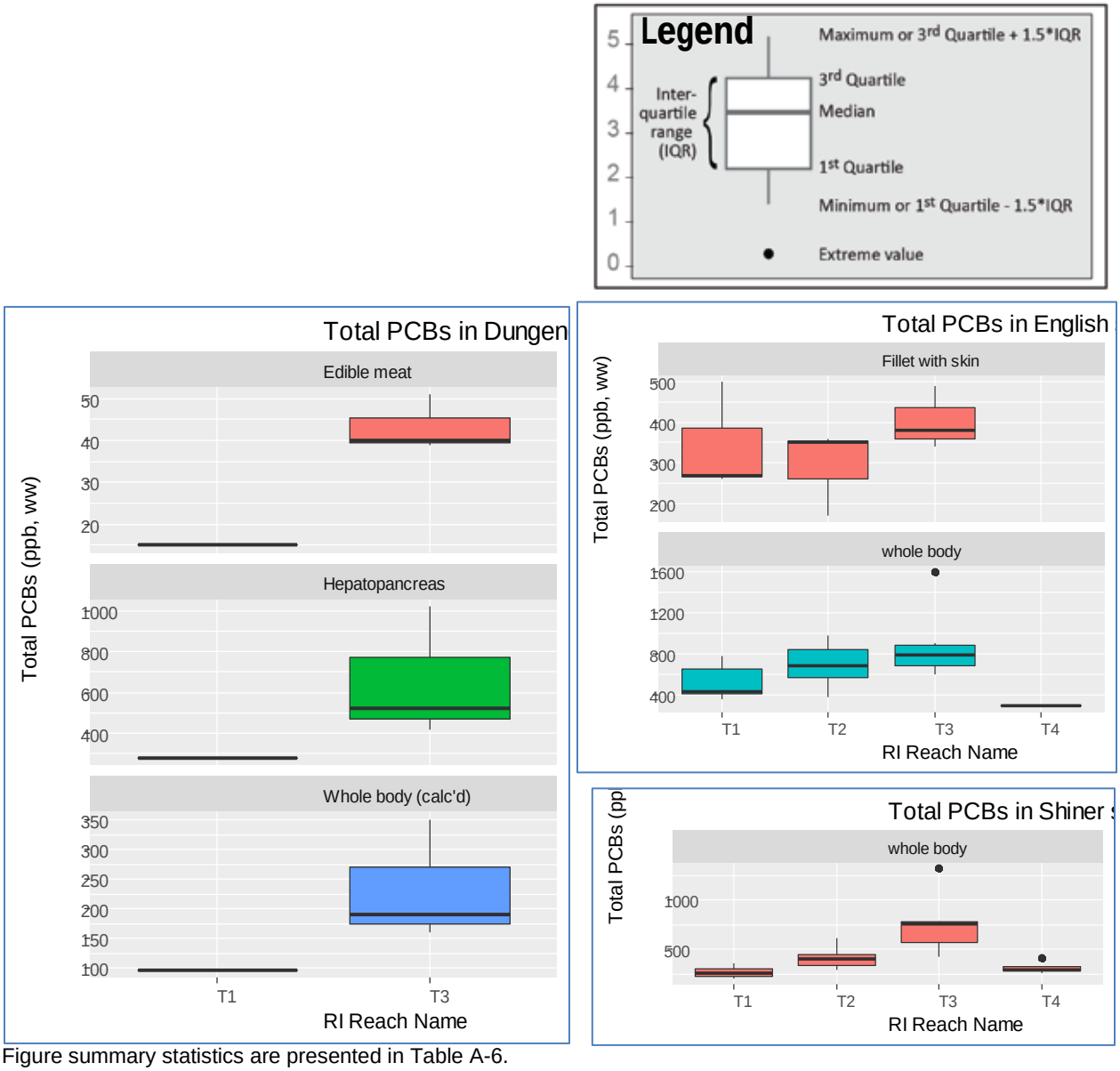


Figure summary statistics are presented in Table A-6.

Figure A-4. Boxplots showing the distribution by reach of total PCBs (ppb, ww) within each species and tissue type for samples in the RI dataset

A GOF test (Shapiro-Wilk's test for normal distribution) and probability plots (QQ plots) were used to evaluate the distribution of each tissue type for each species. Due to the small sample sizes within each RI reach and evidence that a stratified model was appropriate for the site-wide mean (Table A-6 and Figure A-4), residuals from the stratified model (the differences between each observation and the reach mean) were combined across all RI reaches to evaluate the statistical distribution for each species and tissue type.

The GOF results are presented in Section 4.3. The best-fit distribution from the GOF evaluation and estimates of the CV for each tissue type and species were used to generate plots illustrating the expected RME of the mean as a function of sample size (Section 4.5).

4.3 FISH AND CRAB TISSUES RESULTS

Composite tissue concentrations for each species and tissue type appeared to be approximately normally distributed, based on Shapiro-Wilk's GOF test (Table A-7) and normal probability plots (Figure A-5). Both of these evaluations used the residuals from a stratified model, after excluding two high values identified as outliers (one for English sole, whole body, and one for shiner surfperch, whole body). When the outliers were included, they dominated the probability plots and caused the normality assumption to be rejected. If the tissue data from the baseline sampling effort is skewed, a gamma distribution may be a more appropriate model. Consequently, sample size estimates for both normal and skewed gamma distributions are presented in Section 4.5.

Table A-7. Results of the GOF tests on residuals pooled across RI reaches, reported by species and tissue type

Species	Tissue Type	N	Shapiro-Wilk's p-value	Comment
Dungeness crab	edible meat	4	0.31	insufficient data to assess distribution
	whole body (calc'd)	4	0.50	insufficient data to assess distribution
English sole	fillet with skin	9	0.53	data look normal
	whole body	18	0.63	normality rejected for all data; results shown excluding outlier at 1,600 ppb
Shiner surfperch	whole body	21	0.94	normality rejected for all data; results shown excluding outlier at 1,330 ppb

Note: Residuals are the differences between each composite value observation and the mean value of the RI reach.
GOF – goodness-of-fit
ppb – parts per billion
RI – remedial investigation

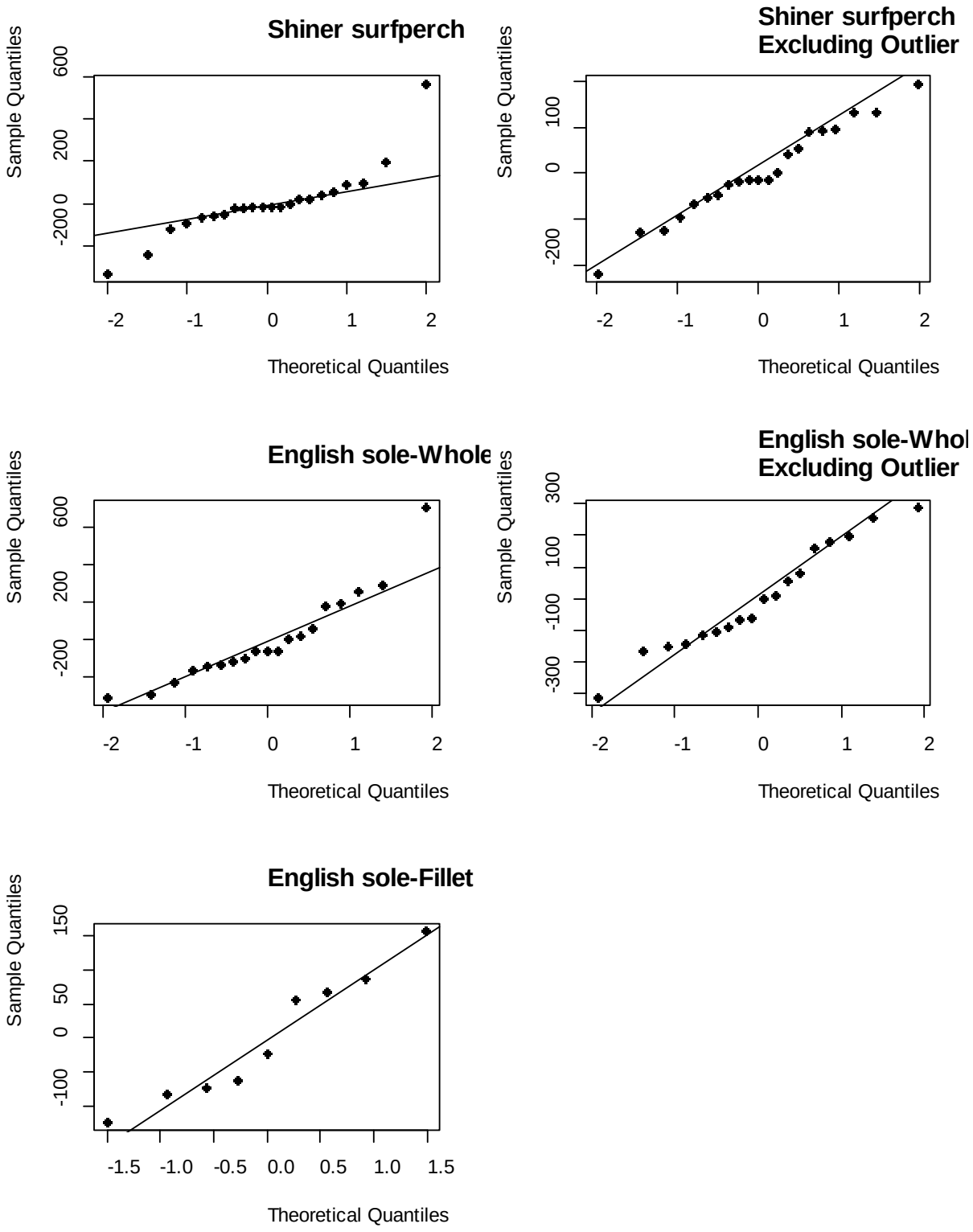


Figure A-5. Normal probability plots of the concentration residuals within each RI reach, by species and tissue type for Shiner surfperch and English sole

The compositing methods used in the RI will be modified for the baseline sampling in order to meet the more general objectives of the baseline sampling, and also to reduce variance and the possibility for extreme values. Each composite sample will be comprised of individuals collected throughout the entire reach rather than within smaller subareas. The number of individuals per composite will be increased from 5 to 10 English sole and from 10 to 15 shiner surfperch. More individual crabs per composite sample will not be targeted because of the difficulty in catching the targeted size of Dungeness crab in the LDW.

The changes to the sampling approaches for English sole and shiner surfperch are expected to reduce variance and improve normality from what was observed in the 2007 dataset. The relationship between RME and sample size was calculated and presented for both a normal and a skewed (gamma) distribution (Section 6.2).

The targeted sample size can be identified for each species and tissue type using the curve associated with the appropriate CV value. The applicable CV values derived from the RI dataset were presented in Table A-6 and are discussed in more detail below:

- **Dungeness crab – edible meat**: CV ≤ 25%. There were only three Dungeness crab edible meat composites in the 2007 dataset from which variance could be estimated. These three composites from RI reach T3 had a CV of 15%. Additional information from the 2004 dataset indicated that composite samples from reaches T1 and T3 (n = 3 each) both had CVs of 20%. In 2007, there appeared to be differences in concentrations among reaches, justifying the use of a stratified mean.
- **Dungeness crab – whole body (calculated[17])**: CV < 60%. There were only three Dungeness crab (calculated) whole-body composites in the 2007 dataset from which variance could be estimated. These three composites from R1 reach T3 had a CV of 44%, an estimate that was heavily influenced by a single high hepatopancreas result.[18] Additional information from the 2004 and 2005 datasets suggests variability in the calculated whole-body crab values may be much lower than was observed in 2007. The site-wide CV of calculated whole-body values was 12% in 2004 (n = 7), 4% in 2005 (n = 3), and 15% in 2007 when the outlier was excluded. It appears that there may be much less variability among calculated whole-body crab estimates than suggested by the 2007 results alone, so a CV of 60% represents an extreme upper bound, and the actual value is expected to be much lower. Concentration differences were apparent among reaches, lending support to the use of a stratified mean.

[17] Each whole-body crab composite concentration was calculated as the weighted sum of separate hepatopancreas and edible meat composites from the same crabs.

[18] The three hepatopancreas results were 420, 520, and 1020 µg/kg wet weight (ww).

- **English sole – fillet with skin**: CV ≅ 30%. Variance was based on three composites from each of three RI reaches (T1, T2, and T3). There did not appear to be strong differences in concentrations among reaches. Therefore, if the data support using a single population estimate (instead of a stratified estimated), this approach will gain one additional degree of freedom. Increasing the number of individuals per composite from 5 to 10 should reduce the variability in the baseline survey from what was observed in 2007.
- **English sole – whole body**: CV ≅ 40%. Variance was based on six composites from each of three RI reaches (T1, T2, and T3). Increasing the number of individuals per composite from 5 to 10 should reduce the variability in the baseline survey from what was observed in 2007.
- **Shiner surfperch – whole body**: CV ≅ 40%. Variance was based on six composites from each of three RI reaches (T1, T2, and T3) and four composites from RI reach T4. The mean concentrations within each RI reach were different, and the standard deviations increased with the means, supporting the use of a stratified mean. Increasing the number of individuals per composite from 10 to 15 and compositing throughout each reach should reduce the variability in the baseline survey from what was observed in 2007.

4.4 FISH AND CRAB TISSUES 95UCL

The fish and crab tissues will be collected and composited from individual subreaches (shiner surfperch) or reaches (English sole and crab). If it appears that the mean concentrations are different among reaches, stratified estimators will be used to reduce the variance of the site-wide mean.

Using equal weights for each reach, the site-wide mean can be estimated as the grand mean of the mean concentrations within each reach as follows:

$$\overline{\overline{X}} = w \sum_{i=1}^{k} \overline{X_i} \qquad \textbf{Equation 4}$$

Where:

$\overline{X_i}$ is the average concentration in reach i (i = 1 to k, where k = 2 for English sole and Dungeness crab; and k= 4 for Shiner surfperch).

$w = 1/k$ (i.e., ½ for sole and crab, and ¼ for perch).

The sampling variance of the stratified mean is:

$$\widehat{Var}(\overline{\overline{X}}) = w^2 \sum_{i=1}^{k} S^2_{\overline{X}_i} \qquad \textbf{Equation 5}$$

Equation 5 simplifies to the following when each of the *k* reaches are weighted equally:

$$\widehat{Var(\bar{\bar{X}})} = \frac{1}{k^2}\sum_{i=1}^{k} s^2_{\bar{X}_i} \qquad \textbf{Equation 6}$$

Where:

$s^2_{\bar{X}_i} = {}^{s_i^2}/_{n_i}$

s_i^2 is the usual sample variance estimate of the n_i observations in reach i (i = 1 to k, k = 2 for sole and crab, and k = 4 for perch)

n_i is the sample size in reach i

For a stratified mean, the CLT is invoked for the UCL estimate (Levy and Lemeshow 1999), although a more conservative Student's *t*-interval is used instead of a Z-interval due to the uncertainty inherent in small samples with an unknown population variance.

$$95UCL = \bar{\bar{X}} + t_{(0.05,df)} \times SE(\bar{\bar{X}}) \qquad \textbf{Equation 7}$$

Where:

$\bar{\bar{X}}$ is the site-wide mean, as calculated above

SE($\bar{\bar{X}}$) is the standard error of the stratified mean, equal to the square root of the variance estimator in Equation 6

df = the degrees of freedom for this estimator would normally be estimated using Satterthwaite's formula which is a function of variance. For the purposes of this *a priori* sample size estimation, the degrees of freedom will be set to $N - k$ (N = the total number of samples site-wide, k = the number of strata)

If the population does not appear to have different means or variances within the different reaches, then the results from all reaches will be pooled for greater power. These pooled data may either be approximately normally distributed (Equation 1), or gamma distributed, which uses the following equations.

$$Approximate\ 95UCL = 2n\hat{k}\bar{X}/\chi^2_{(0.05,df=2n\hat{k})} \qquad \textbf{Equation 8}$$

Where:

$\hat{k}$ is the shape estimator for the gamma distribution

$\bar{X}$ is the mean

$\chi^2_{(0.05,df=2n\hat{k})}$ is the 5th quantile of the chi-square distribution (i.e., 5% of the area is in the left tail), with $2n\hat{k}$ degrees of freedom

For a gamma distribution, the mean and SD are functions of the scale and shape parameters, Θ and k, as: $\bar{X} = \Theta k$ and $SD = \Theta\sqrt{k}$. Thus, the CV = $\Theta\sqrt{k}/\Theta k = 1/\sqrt{k}$ and $k = 1/CV^2$, and Equation 9 expressed in terms of the CV reduces to the following (EPA 2013):

$$\textit{Approximate } 95UCL = \frac{2n}{CV^2}\bar{X}/\chi^2_{(0.05,df=2n/CV^2)} \qquad \textbf{Equation 9}$$

And the RME as a proportion of the mean is:

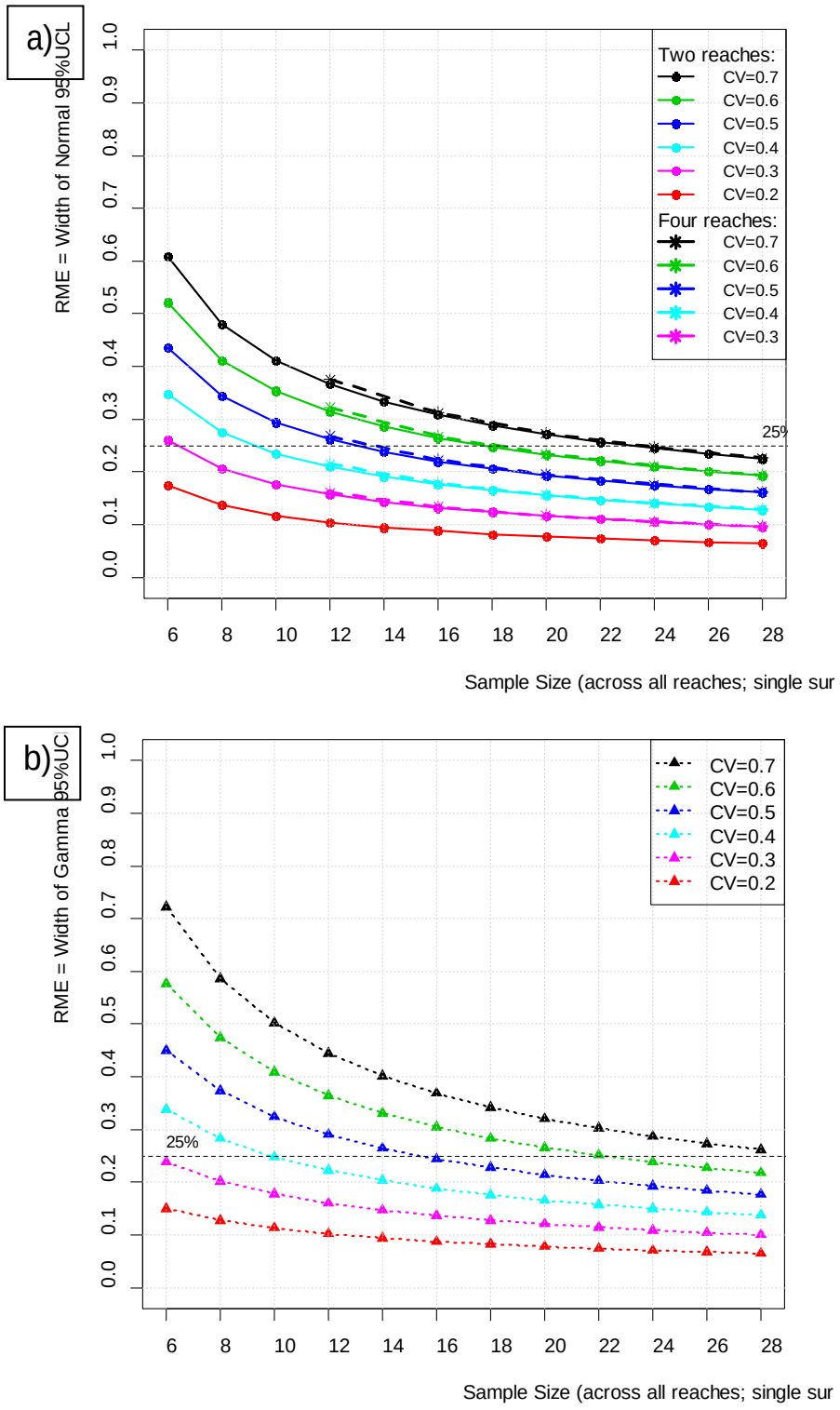
$$RME = \frac{(\frac{2n}{CV^2}\bar{X}/\chi^2_{(0.05,df=2n/CV^2)} - \bar{X})}{\bar{X}} = \frac{2n}{CV^2}/\chi^2_{(0.05,df=2n/CV^2)} - 1 \qquad \textbf{Equation 10}$$

4.5 FISH AND CRAB DISCUSSION

The sampling design for fish and crab tissues is intended to meet the RME target of 25% for the site-wide means, except for whole-body crab, which may have an RME as high as 30%.

The distribution of the fish and crab tissue composites was observed to have outliers in some of the tissue types (Section 4.3). The increase in the number of fish per composite and inclusion of fish across a larger area for each composite is expected to reduce the chance of outliers justifying the use of Student's t-interval for the 95UCL (Equation 7). If the baseline data are skewed, the use of a gamma distribution 95UCL will be more appropriate (Equation 9). The CVs assumed to be most applicable for these data (Section 4.3) are all less than 0.4, with the exception of the Dungeness crab (calculated) whole-body estimate (CV ≤ 0.6 using all data, and CV < 0.15 excluding the outlier).

Figure A-6 illustrates the relationship between the total number of composite samples and the RME, for normal, stratified estimators of the mean (Figure A-6a) and for a single gamma-distributed population (Figure A-6b), for a range of CVs. Results are displayed for two strata (applicable to English sole and Dungeness crab) and four strata (applicable to shiner surfperch).



Shown for a range of CVs for samples balanced across two or four reaches.

Figure A-6. RME for two or four strata, using a normal UCL (top) and for a single population using a gamma UCL (bottom) versus total sample size

A site-wide total of 12 composite samples of each tissue type for English sole (6 in each of 2 reaches) and shiner surfperch (3 in each of 4 subreaches) is expected to meet the target RME of 25% or better for these species and tissue types, based on CVs of 0.4 or less.[19] The CVs observed in the 2007 dataset were 0.3 to 0.4 for these tissue types, and baseline sampling is expected to be less variable because more individuals will be included in each of the composite samples. If the CV in baseline tissue is greater than anticipated, the analysis of archived tissue, as available, may be recommended (see Section 4.1.2 of the fish and crab QAPP (Windward 2017a)).

A site-wide total of 12 composite samples for Dungeness crab edible meat (6 in each of 2 reaches) are expected to meet a target RME of approximately 10%, based on a CV of 0.2. The whole-body (calculated) results had high variability in the 2007 dataset (CV of 0.6, Table A-6), but this was influenced by a single high hepatopancreas sample. Information from the 2004 and 2005 datasets suggests that the CV may be much lower (≤ 0.12). All the previous datasets had small sample sizes (n ≤ 3 per reach) due to the difficulty of catching Dungeness crab in the LDW; as a result, the CV estimates are fairly uncertain, ranging from 0.04 in 2004 to 0.62 in 2007, which included an outlier. Based on a CV of 0.6 for the site-wide mean, the RME for whole-body Dungeness crab may be as high as approximately 30%, or less than 10% (based on a CV of 0.15, calculated excluding the outlier).

5 Clam Tissues

The clam tissue sampling effort is designed to estimate the LDW-wide 95UCL concentrations for comparison to TTLs related to RAO 1 (ROD Table 21[20] (EPA 2014)). There will be 1 composite tissue sample[21] for each of the 11 clam collection areas[22] (Map 3-10 of the main document). The site-wide variability for these tissues is currently unknown, so no target RME has been established for these data. The variability observed during baseline sampling can be used to set precision goals for future sampling efforts.

Eleven composite tissue samples will be collected during baseline sampling, each sample being representative of a single local clam tissue collection area. The 11 samples will be used to calculate the site-wide 95UCL for comparison to target tissue levels. This approach assumes each clam collection area is equally likely to be visited by any person at any point in time over the 30- (non-tribal) and 70-year (adult tribal) exposure periods.

[19] Refer to blue shaded rows in Table A-6 for the appropriate CVs for the stratified mean.
[20] ROD Table 21 is titled *LDW resident fish and shellfish target tissue concentrations.*
[21] For arsenic, there will be composite samples of two tissue types (siphon skin and main body minus the siphon skin) from each beach; for all other COCs, there will be composite samples of only one type (whole body), depending on the results of the cPAH clam siphon effort (LDWG 2017).
[22] If clams are not present in clam collection areas within recently remediated areas (i.e., Slip 4, Terminal 117), fewer than 11 areas will be sampled.

Once these data are available, the distribution will be assessed using GOF tests and probability plots. The 95UCL will be calculated using the most appropriate methods based on the observed distributional characteristics (i.e., distributional form, number of non-detects).

6 Surface Water

The surface water sampling effort is designed, in part, to assess trends in PCB concentrations in surface water. Passive samplers will be deployed at one location in the LDW (RM 3.3).

With limited data available to estimate the variability that the passive samplers will detect in surface water concentrations in the LDW, no target RME was established for this sampling component. Instead, the sampling design was developed using a conceptual model for contaminants in surface waters in the LDW and other available information.

Similar to the surface sediment and tissue sampling efforts, several methods may be used to assess trends for surface water. For example, a simple graphical presentation of surface water concentrations collected over time with an estimate of the slope (or non-parametric correlation) that describes the temporal trend: this would be the simplest way to assess trends, but it would provide only an estimation, and would lack predictions regarding the size of the temporal change or its statistical significance. Another method, which would rely on a statistical test, would compare the mean surface water concentrations from baseline to those in a future sampling period; the sampling design established for this method would provide sufficient statistical power to detect a difference of a meaningful size. The conceptual approach presented herein may be used equally well with either of the described approaches, or others, in a long-term monitoring program. An approximation of the statistical power for this sampling design to detect changes from baseline is provided in Section 6.2 using published data (Apell and Gschwend 2017).

6.1 Surface Water Data Used in the Analysis

As described in more detail in the draft Work Plan (Windward and Integral 2017), the LDW is an estuarine system with a well-stratified salt wedge that is influenced by both freshwater from the Green River upstream and a tidal influx of denser saltwater from Elliott Bay. PCB concentrations in surface water in both the LDW and upstream areas are greater than the lowest applicable or relevant and appropriate requirement (ARAR) identified in the ROD (Tables A-8 and A-9) and are variable (Figure A-7). This variability depends on river conditions, recent precipitation, and the patterns of estuarine circulation.

Table A-8. Summary of ARARs and existing surface water data for PCBs

	PCB Concentration in Surface Water (ng/L)		Notes/Source
	Average	Range	
ARARs:			
WQC – human health[a]	0.064		organism-only and organism + water criteria
WQC – aquatic criteria	30 (chronic)		marine criteria
Washington State aquatic criteria	10,000 (acute); 30 (chronic)		marine criteria
Upstream (Windward 2017b):			
RM 6.3 – Green River	0.130	0.045–0.514	n = 9; March 2007 to December 2007
RM 10 – Green River[b]	0.618	0.045–6.936	n = 40; September 2011 to February 2015
RM 12.4 – Green River	0.538	0.024–2.434	n = 23; August 2005 to August 2008
LDW (Windward 2010b):			
RM 0.0 – surface (LTKE03)	1.34	0.591–1.947	n = 4; August 2005 to December 2005 (see Table A-2)
RM 0.0 – deep (LTKE03)	0.888	0.250–1.814	n = 3; August 2005 to December 2005 (see Table A-2)
RM 3.3 – surface (LTUM03)	1.14	0.398–1.529	n = 4; August 2005 to December 2005 (see Table A-2)
RM 3.3 – deep (LTUM03)	1.64	0.132–3.211	n = 4; August 2005 to December 2005 (see Table A-2)

[a] ARAR was the most stringent value from the WQC in WAC 173-201(a), NTR, and AWQC at the time of the ROD.

[b] A subset of the samples collected by King County for this RM were biased high due to equipment contamination. These samples were included in the average, but did not impact the range of concentrations presented. Work is ongoing to determine how to correct for this issue (Williston 2017).

ARAR - applicable or relevant and appropriate requirement
AWQC – ambient water quality criteria
LDW – Lower Duwamish Waterway
NTR – National Toxics Rule
PCB - polychlorinated biphenyl
RM – river mile
ROD – Record of Decision
WAC – Washington Administrative Code
WQC – water quality criteria

Table A-9. LDW surface water data for total PCBs (sum of PCB congeners)

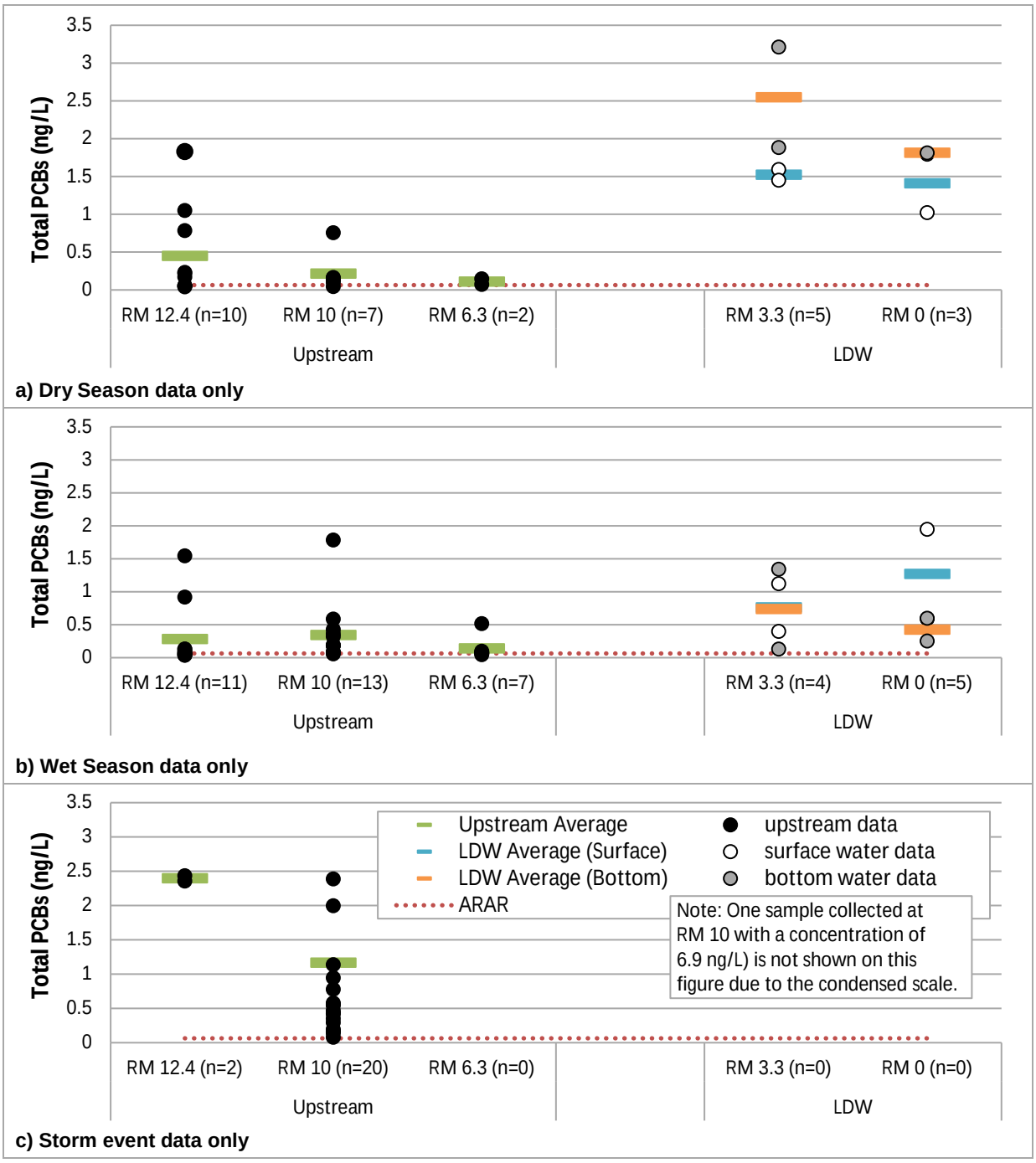
Sample Type[c]	Total PCB Concentration and Salinity by Date[a]											
	Dry Season Samples						Wet Season Samples					
	8/22/2005 (277 cfs)[b]			9/26/2005 (378 cfs)[b]			11/28/2005 (1,060 cfs)[b]			12/19/2005 (550 cfs)[b]		
	Total PCBs (ng/L)	Salinity (PSS)	TSS (mg/L)	Total PCBs (ng/L)	Salinity (PSS)	TSS (mg/L)	Total PCBs (ng/L)	Salinity (PSS)	TSS (mg/L)	Total PCBs (ng/L)	Salinity (PSS)	TSS (mg/L)
LTKE03 (RM 0.0)												
Surface	1.796	22.984	4.8	1.024	25.174	6.0	0.591	13.388	4.2	1.947 J	25.987	5.05
Deep	1.814	28.273	3.1	nc[c]	30.266	3.7	0.25	30.118	2.0	0.599	29.995	2.9
LTUM03 (RM 3.3)												
Surface	1.592 J	16.523	3.4	1.452 J	17.133	5.0	0.398	9.929	4.3	1.122	9.423	4.34
Deep	3.211	26.043	11.1	1.883 J	29.402	5.8	0.132	20.362	4.2	1.341	27.775	3.7

[a] Total PCB concentration represents the sum of detected PCB congener concentrations. RLs for non-detects were not included in the calculation. Data management procedures and data validation criteria were used to calculate the total PCB concentrations presented in the King County technical memorandum (Mickelson and Williston 2006).

[b] Daily mean discharge flow rate in the Green River at USGS Gauge 12113000 in Auburn, Washington.

[c] A number of PCB congener results were rejected because method performance criteria were not met during analysis; therefore, total PCB concentrations were not calculated.

cfs – cubic feet per second
J – estimated concentration
nc – not calculated
PCB – polychlorinated biphenyl
PSS – practical salinity scale
RL – reporting limit
RM – river mile
TSS – total suspended solids
USGS – US Geological Survey



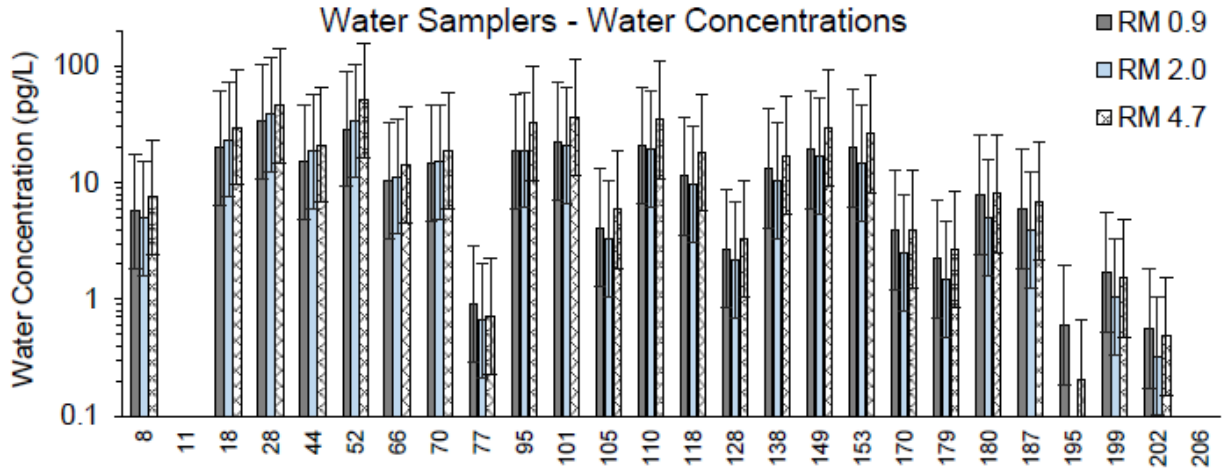
Notes: Storm event data were defined as data from any day with 0.25 in. or more of rainfall. Dry and wet season data were determined based on best professional judgment using information regarding season and rainfall. The ARAR was 0.064 ng/L for human health WQC at the time of the ROD. Surface and bottom water data shown are from the LDW because of the two-layer estuarine flow and greater depth. The upstream data were collected from mid-depth.

Figure A-7. Total PCB concentrations in upstream and LDW surface water samples

The data for PCBs in LDW surface water in Tables A-8 and A-9 and Figure A-7 were from whole-water grab samples. PCB concentrations in whole-water samples are quite variable. Another method to assess PCB concentration trends in surface water is to monitor freely dissolved PCB concentrations using passive sampling devices.

Passive samplers were deployed at three locations (RM 0.9, RM 2.0, and RM 4.7) to evaluate surface water concentrations in the LDW (Apell and Gschwend 2017).

Three replicates samplers were deployed 1 m below the water surface at each location for approximately eight weeks (June 2 to July 27, 2015), after which the samples (referred to as near-surface samples in that study) were analyzed for PCB congeners. As shown in Figure A-8, PCB congener concentrations were similar at the three sampling locations,[23] whereas variability among the concentrations across the three replicates was greater (variability was shown by error bars that represented 95th percentile confidence intervals).



Source: Apell and Gschwend (2017); Figure S4. Error bars represent the 95% confidence intervals for the mean by location.

Figure A-8. Freely dissolved PCB congener concentrations derived from passive samplers deployed in the LDW 1m below the water surface

6.2 SURFACE WATER METHODS

Baseline data for freely dissolved PCB concentrations in surface water will be compared with future long-term monitoring data as follows. An *a priori* power analysis will be used to identify the number of replicate samples expected to provide a reasonable detectable difference for this comparison. *A priori* power analyses are predictive, describing a scenario for an expected result with a given level of confidence; the accuracy of this prediction in a particular situation is dependent on whether the

[23] The uncertainty analysis included an assessment of uncertainties associated with analytical measurements and partition coefficients.

assumptions that were made about mean and variance are valid. The estimated replicate sample size identified through the power analysis will rely on limited existing information about the variability expected among field replicates in passive samplers in the LDW.

The baseline mean concentrations will be estimated as the average of replicates over two dry-season passive sampler deployments; the future mean concentrations (i.e., post-remedy) will be estimated as the average of replicates over two dry-season deployments at the same location. For example, if baseline data are collected in August 2017 and August 2018, these data will be compared with future data collected over two consecutive dry-season passive sampler deployments.[24]

The data generated during baseline characterization and any future sampling period may be compared using a parametric *t*-interval for an equation that estimates the difference between the means of two time periods (i.e., a two-tailed, two-sample comparison, similar to a simple *t*-test but modified to use estimates of mean and standard error [SE] that are appropriate for the sampling design and difference equation being tested). This comparison between the future and baseline summer means for a single station and depth is a two-tailed hypothesis test that has the following null and alternative hypotheses:

$$H_0: \mu_{future} = \mu_{baseline}$$

Vs.

$$H_a: \mu_{future} < \mu_{baseline} \text{ or } \mu_{future} > \mu_{baseline}$$

When the grand mean (a mean of two annual means) from baseline sampling is compared to the grand mean from a future timeframe, the difference equation (Δ) can be written as:

$$\Delta = \frac{1}{2}(\bar{S}_{B1} + \bar{S}_{B2}) - \frac{1}{2}(\bar{S}_{F1} + \bar{S}_{F2}) \qquad \textbf{Equation 11}$$

Where:

$\bar{S}_{Bj}$ = mean for a given station and depth during baseline year j (j=1 or 2)

$\bar{S}_{Fj}$ = mean for the same station and depth during future year j (j=1 or 2)

Replication occurs within the station, depth, and year, such that the variability among field replicates within a station is the scale against which the difference in means (Equation 11) is evaluated. Using the relationship that the variance of a sum is the sum

[24] The need for data from two consecutive dry seasons will be evaluated over time.

of the variances for independent samples, the SE of this difference equation is estimated as:

$$\widehat{SE(\Delta)} = \sqrt{\sum_j c_j^2 S_j^2 / n_j} \qquad \textbf{Equation 12}$$

Where:

c_j = coefficient for the j^{th} mean in the difference equation (Equation 11), either ½ or -½

S_j^2 = variance among field replicates for the j^{th} sampling period; if variances are equal, a single pooled residual variance estimate, S_p^2, can be used for each group

n_j = number of field replicates within the j^{th} sampling period; replication is designed to be equal within every sampling period and location, but sample sizes may be unequal in the final analysis if samplers are lost

To establish the number of samples needed to provide an expected minimum detectable difference (MDD) between a baseline mean and a future mean, the following relationship is used:

$$MDD \geq \widehat{SE(\Delta)}\left(t_{\alpha(2),df} + t_{\beta(1),df}\right) \qquad \textbf{Equation 13}$$

Assuming equal variances and equal n during all sampling periods, this simplifies to:

$$MDD/S_p \geq \left(t_{\alpha(2),df} + t_{\beta(1),df}\right)/\sqrt{n} \qquad \textbf{Equation 13a}$$

This is the scaled MDD (i.e., the MDD expressed in units of the square root of the pooled residual variance), where:

df = the degrees of freedom associated with the standard error estimate (Equation 12)

Types I (α) and II (β) errors = 10%

When the scaled MDD is multiplied by the baseline coefficient of variation (CV = SD / mean), and it is assumed that the baseline SD is similar to the pooled residual SD (S_p), then the MDD is expressed as a percentage of the baseline mean:

$$MDD/S_p \times S_p/Mean = (Mean_{Baseline} - Mean_{Future})/Mean_{Baseline}$$

$$\geq CV \times \left(t_{\alpha(2),df} + t_{\beta(1),df}\right)/\sqrt{n} \qquad \textbf{Equation 13b}$$

If the data must be log-transformed to meet the normality assumption for the residuals, then the MDD is the minimum difference between the mean of the log-scale values that would be detected with the specified Type I and II error rates. Exponentiation of the log-scale MDD (MDD′) yields:

$$exp(MDD') = exp\left(Mean_{log(Baseline)} - Mean_{log(Future)}\right)$$

$$= GeoMean_{Baseline}/GeoMean_{Future} \qquad \textbf{Equation 14}$$

And

$$(GeoMean_{Baseline} - GeoMean_{Future})/GeoMean_{Baseline}$$

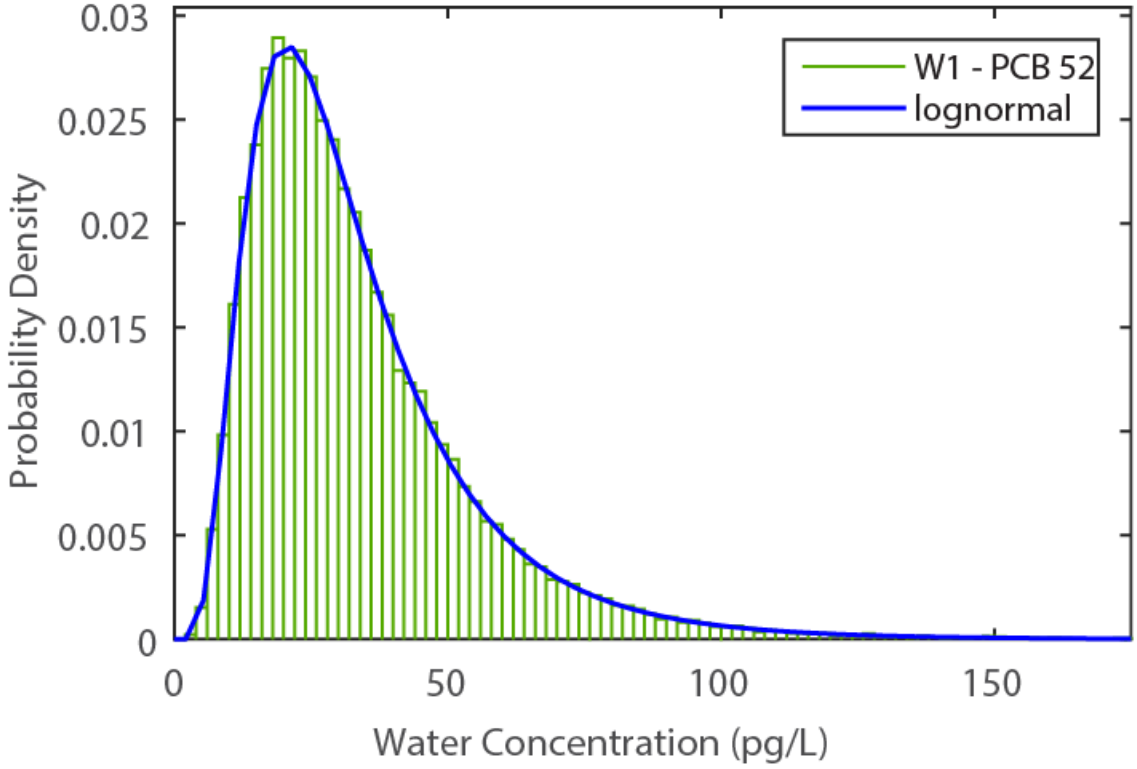
$$= 1 - 1/exp(MDD') \qquad \textbf{Equation 14a}$$

Where:

$GeoMean_p$ = the geometric mean for period p

Hence, MDD′ for log-transformed data is computed using Equation 13a, the result of which is then converted to a percent difference of geometric means on the original scale using Equation 14a.

The estimated water concentrations from passive samplers are likely to be approximately left skewed (log-normal) for some individual congeners, due to log-normal errors in the estimated partition coefficients that are used to estimate the water concentrations. Figure A-9 (Figure S6 from Apell and Gschwend (2017)) shows the results for a single PCB congener with simulated analytical errors. The estimate of total PCBs is a sum of congeners, which may also be left skewed. Power results are presented assuming both normal and log-normal distributions for the data.



Source: Figure S6 in Apell and Gschwend (2017)

Figure A-9. Histogram and fit of PCB-52 water concentrations measured with passive samplers when the error is propagated with a randomized simulation

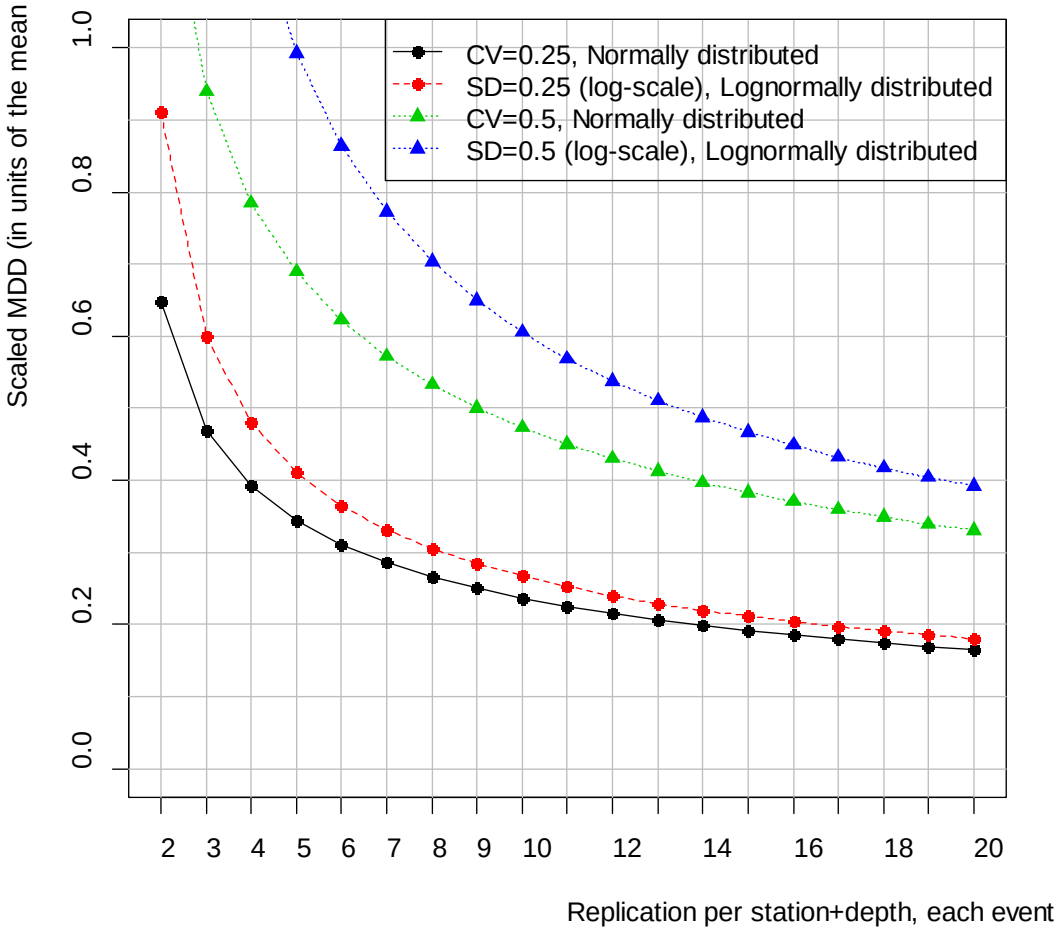
Analytical results that are approximately normally distributed may be compared using a *t*-interval, and the relationship between sample size and MDD as a percent of the baseline mean is described by Equation 13b. On the other hand, if the water concentration results are log-normally distributed, then the comparison would use a *t*-interval for the log-transformed data, and the relationship between sample size and MDD of the geometric means as a percent of the baseline geometric mean would use the relationship shown in Equation 14a.

6.3 SURFACE WATER RESULTS

In the LDW, the CV for total PCBs measured in three passive samplers to be placed at approximately RM 0.9, RM 2.0, and RM 4.7 was inferred to be on the order of 25% (based on the results provided in Apell and Gschwend (2017)[25]). Figure A-10 shows the

[25] In Apell and Gschwend (2017), total PCBs appear to be a sum of 27 PCB congeners. RKM 1.4, RKM 3.2, and RKM 7.6 reported in the document are equivalent to RM 0.9, RM 2.0, and RM 4.7, respectively, and the CV was approximated for the three samples based on a reported range from 0.28 to 0.42 ng/L and a

MDD as a percent of the baseline mean for both a normal and log-normal assumption regarding the data distribution. For a normal distribution, the MDD expressed as a percent of the baseline mean assumes a CV of 25% for field replicates; for a log-normal distribution, the MDD assumes a log-scale SD of 0.25.[26] Additional curves are shown for a CV of 50% and a log-scale SD of 0.5 to reflect the possibility that field variability is much higher than that expressed by the limited data that is currently available.



Note: Assumes a parametric *t*-interval test for the difference of means between baseline (2 years) and future (2 years) for data that are either normally or log-normally distributed. Types I and II errors are both set at 10%. The CV and log-scale SD values of 0.25 are comparable to reported field variability.

Figure A-10. Relationship between replication within each station/depth and sampling event versus scaled MDD (expressed in units of the mean)

With a balanced design (2 years in baseline and 2 years in the future), 9 field replicates from each sampling event (for a total of 18 results during the 2 baseline years, and

geometric mean of 0.32 ng/L. The middle result was estimated as 0.28 ng/L; so SD (0.28, 0.28, 0.42) / mean (0.28, 0.28, 0.42) = 25%.

[26] SD(log(0.28), log(0.28), log(0.42)) = 0.23, which is rounded up to 0.25.

18 results during the 2 future years) are expected to result in an MDD equivalent to approximately 25% of the baseline mean if the CV = 0.25, and 50% of the mean if the CV = 0.5, for normally distributed data. If the data are log-normally distributed, the predicted MDD is higher, ranging from 28 to 65% of the baseline geometric mean (for log-scale SDs of 0.25 and 0.5, respectively).

Assuming a mean (or geometric mean) baseline value of approximately 0.32 ng/L for total PCBs in the LDW (Apell and Gschwend 2017), nine field replicates from one station (for both each of 2 years in baseline and each of 2 years in the future) are expected to result in a detected a minimum difference of approximately 0.1 ng/L (using field variability reported by Appel and Gschwend, and either a normal or log-normal distribution).

7 References

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APPENDIX B. ANALYTICAL METHODS AND REPORTING LIMITS

Tables

This appendix contains a subset of the tables with reporting limit goals and methods. The remaining tables of this type are included in the main text of the work plan. Tables were included in this appendix if they were for conventional parameters, components of sums, or of great length.

Table B-1. Methods and RLs for conventional analyses

Analyte	Matrix	Method	Unit	RL
TOC	sediment	PSEP 1986 Combustion IR	% dw	0.0200
Total solids	sediment	SM 2540 G-97	% dw	0.040
Grain size	sediment	PSEP 1986	% dw	0.1
Lipids	tissue	Bligh and Dyer (mod)	% ww	0.010
Total solids	tissue	PSEP 1986	% dw	0.040
Salinity	surface water	SM 2520 B-00	ppt	0.1
TSS	surface water	SM 2540 D-97	mg/L	1.0
TOC	surface water	SM 5310 B-00	mg/L	0.500
DOC	surface water	SM 5310 B-00	mg/L	0.500

dw – dry weight
DOC – dissolved organic carbon
ppt – parts per thousand
PSEP – Puget Sound Estuary Program
RL – reporting limit
SM – Standard Methods
TOC – total organic carbon
TSS – total suspended solids
ww – wet weight

Table B-2. Method and RL goals for cPAHs in tissue

Analyte	Method	Unit	RL	PEF	TEQ[a]
cPAHs[b]					
Benzo(a)anthracene	EPA 8270D-SIM	µg/kg ww	5.00	0.1	0.25
Benzo(a)pyrene	EPA 8270D-SIM	µg/kg ww	5.00	1	2.5
Benzo(b)fluoranthene	EPA 8270D-SIM	µg/kg ww	5.00	0.1	0.25
Benzo(k)fluoranthene	EPA 8270D-SIM	µg/kg ww	5.00	0.1	0.25
Chrysene	EPA 8270D-SIM	µg/kg ww	5.00	0.01	0.025
Dibenzo(a,h)anthracene	EPA 8270D-SIM	µg/kg ww	5.00	0.4	1
Indeno(1,2,3-cd)pyrene	EPA 8270D-SIM	µg/kg ww	5.00	0.1	0.25

[a] TEQ calculated using ½ RL value multiplied by the PEF.

[b] Target tissue level for cPAH (µg TEQ/kg ww) is 0.24 for clams. The cPAH TEQ RL goal is 4.5 (µg TEQ/kg ww).

cPAH – carcinogenic polycyclic aromatic hydrocarbon
EPA – US Environmental Protection Agency
PEF – potency equivalency factor
RL – reporting limit
SIM – selective ion monitoring
TEQ – toxic equivalent
ww – wet weight

Table B-3. Method and RL goals for organochlorine pesticides that are components of sums in tissue

Analyte	Method	Unit	RL
Chlordanes			
alpha-Chlordane	EPA 8270D/1699 Mod	µg/kg ww	1.0
cis-Nonachlor	EPA 8270D/1699 Mod	µg/kg ww	1.0
gamma-Chlordane	EPA 8270D/1699 Mod	µg/kg ww	1.0
Oxychlordane	EPA 8270D/1699 Mod	µg/kg ww	2.5
trans-Nonachlor	EPA 8270D/1699 Mod	µg/kg ww	1.0
DDx Compounds			
2,4'-DDD	EPA 8270D/1699 Mod	µg/kg ww	2.5
2,4'-DDE	EPA 8270D/1699 Mod	µg/kg ww	2.5
2,4'-DDT	EPA 8270D/1699 Mod	µg/kg ww	1.0
4,4'-DDD	EPA 8270D/1699 Mod	µg/kg ww	1.0
4,4'-DDE	EPA 8270D/1699 Mod	µg/kg ww	2.5
4,4'-DDT	EPA 8270D/1699 Mod	µg/kg ww	1.0

DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
EPA – US Environmental Protection Agency
RL – reporting limit
total DDx – sum of all six DDT isomers (2,4′-DDD, 4,4′-DDD, 2,4′-DDE, 4,4′-DDE, 2,4′-DDT and 4,4′-DDT)
ww – wet weight

Table B-4. Method and RL goals for chlordanes in water

Analyte	Method	Units	MDL	RL
Chlordanes				
alpha-Chlordane	EPA 8081B	µg/L	0.00820	0.025
cis-Nonachlor	EPA 8081B	µg/L	0.0950	0.050
gamma-Chlordane	EPA 8081B	µg/L	0.00820	0.025
Oxychlordane	EPA 8081B	µg/L	0.0356	0.050
trans-Nonachlor	EPA 8081B	µg/L	0.00860	0.050

EPA – US Environmental Protection Agency
MDL – method detection limit
RL – reporting limit

Table B-5. Method and RL goals for PCB congeners in water, sediment, and tissue

Analyte	EPA Method 1668C					
	Water (pg/L) Based on 1-L sample		Sediment[c] (ng/kg dw) Based on 10-g sample		Tissue[d] (ng/kg ww) Based on 10-g sample	
	EDL[a]	LMCL[b]	EDL	LMCL	EDL	LMCL
PCB-1	1.0	4.0	0.1	0.4	0.1	0.4
PCB-2	1.0	4.0	0.1	0.4	0.1	0.4
PCB-3	1.0	4.0	0.1	0.4	0.1	0.4
PCB-4	2.0	4.0	0.2	0.4	0.2	0.4
PCB-5	2.0	4.0	0.2	0.4	0.2	0.4
PCB-6	2.0	4.0	0.2	0.4	0.2	0.4
PCB-7	2.0	4.0	0.2	0.4	0.2	0.4
PCB-8	2.0	4.0	0.2	0.4	0.2	0.4
PCB-9	2.0	4.0	0.2	0.4	0.2	0.4
PCB-10	2.0	4.0	0.2	0.4	0.2	0.4
PCB-11	2.0	4.0	0.2	0.4	0.2	0.4
PCB-12/13	2.0	4.0	0.2	0.4	0.2	0.4
PCB-14	2.0	4.0	0.2	0.4	0.2	0.4
PCB-15	2.0	4.0	0.2	0.4	0.2	0.4
PCB-16	1.0	4.0	0.1	0.4	0.1	0.4
PCB-17	1.0	4.0	0.1	0.4	0.1	0.4
PCB-19	1.0	4.0	0.1	0.4	0.1	0.4
PCB-21/33	1.0	4.0	0.1	0.4	0.1	0.4
PCB-22	1.0	4.0	0.1	0.4	0.1	0.4
PCB-23	1.0	4.0	0.1	0.4	0.1	0.4
PCB-24	1.0	4.0	0.1	0.4	0.1	0.4

Table B-5. Method and RL goals for PCB congeners in water, sediment, and tissue

Analyte	EPA Method 1668C					
	Water (pg/L) Based on 1-L sample		Sediment[c] (ng/kg dw) Based on 10-g sample		Tissue[d] (ng/kg ww) Based on 10-g sample	
	EDL[a]	LMCL[b]	EDL	LMCL	EDL	LMCL
PCB-25	1.0	4.0	0.1	0.4	0.1	0.4
PCB-26/29	1.0	4.0	0.1	0.4	0.1	0.4
PCB-27	1.0	4.0	0.1	0.4	0.1	0.4
PCB-28/20	1.0	4.0	0.1	0.4	0.1	0.4
PCB-30/18	1.0	4.0	0.1	0.4	0.1	0.4
PCB-31	1.0	4.0	0.1	0.4	0.1	0.4
PCB-32	1.0	4.0	0.1	0.4	0.1	0.4
PCB-34	1.0	4.0	0.1	0.4	0.1	0.4
PCB-35	1.0	4.0	0.1	0.4	0.1	0.4
PCB-36	1.0	4.0	0.1	0.4	0.1	0.4
PCB-37	1.0	4.0	0.1	0.4	0.1	0.4
PCB-38	1.0	4.0	0.1	0.4	0.1	0.4
PCB-39	1.0	4.0	0.1	0.4	0.1	0.4
PCB-41/40/71	1.0	4.0	0.1	0.4	0.1	0.4
PCB-42	1.0	4.0	0.1	0.4	0.1	0.4
PCB-43	1.0	4.0	0.1	0.4	0.1	0.4
PCB-44/47/65	1.0	4.0	0.1	0.4	0.1	0.4
PCB-45/51	1.0	4.0	0.1	0.4	0.1	0.4
PCB-46	1.0	4.0	0.1	0.4	0.1	0.4
PCB-48	1.0	4.0	0.1	0.4	0.1	0.4
PCB-50/53	1.0	4.0	0.1	0.4	0.1	0.4
PCB-52	1.0	4.0	0.1	0.4	0.1	0.4
PCB-54	1.0	4.0	0.1	0.4	0.1	0.4
PCB-55	1.0	4.0	0.1	0.4	0.1	0.4
PCB-56	1.0	4.0	0.1	0.4	0.1	0.4
PCB-57	1.0	4.0	0.1	0.4	0.1	0.4
PCB-58	1.0	4.0	0.1	0.4	0.1	0.4
PCB-59/62/75	1.0	4.0	0.1	0.4	0.1	0.4
PCB-60	1.0	4.0	0.1	0.4	0.1	0.4
PCB-61/70/74/76	1.0	4.0	0.1	0.4	0.1	0.4
PCB-63	1.0	4.0	0.1	0.4	0.1	0.4
PCB-64	1.0	4.0	0.1	0.4	0.1	0.4
PCB-66	1.0	4.0	0.1	0.4	0.1	0.4

Table B-5. Method and RL goals for PCB congeners in water, sediment, and tissue

Analyte	EPA Method 1668C					
	Water (pg/L) Based on 1-L sample		Sediment[c] (ng/kg dw) Based on 10-g sample		Tissue[d] (ng/kg ww) Based on 10-g sample	
	EDL[a]	LMCL[b]	EDL	LMCL	EDL	LMCL
PCB-67	1.0	4.0	0.1	0.4	0.1	0.4
PCB-68	1.0	4.0	0.1	0.4	0.1	0.4
PCB-69/49	1.0	4.0	0.1	0.4	0.1	0.4
PCB-72	1.0	4.0	0.1	0.4	0.1	0.4
PCB-73	1.0	4.0	0.1	0.4	0.1	0.4
PCB-77	1.0	4.0	0.1	0.4	0.1	0.4
PCB-78	1.0	4.0	0.1	0.4	0.1	0.4
PCB-79	1.0	4.0	0.1	0.4	0.1	0.4
PCB-80	1.0	4.0	0.1	0.4	0.1	0.4
PCB-81	1.0	4.0	0.1	0.4	0.1	0.4
PCB-82	1.0	4.0	0.1	0.4	0.1	0.4
PCB-83/99	1.0	4.0	0.1	0.4	0.1	0.4
PCB-84	1.0	4.0	0.1	0.4	0.1	0.4
PCB-88/91	1.0	4.0	0.1	0.4	0.1	0.4
PCB-89	1.0	4.0	0.1	0.4	0.1	0.4
PCB-92	1.0	4.0	0.1	0.4	0.1	0.4
PCB-94	1.0	4.0	0.1	0.4	0.1	0.4
PCB-95/100/93/102/98	1.0	4.0	0.1	0.4	0.1	0.4
PCB-96	1.0	4.0	0.1	0.4	0.1	0.4
PCB-103	1.0	4.0	0.1	0.4	0.1	0.4
PCB-104	1.0	4.0	0.1	0.4	0.1	0.4
PCB-105	1.0	4.0	0.1	0.4	0.1	0.4
PCB-106	1.0	4.0	0.1	0.4	0.1	0.4
PCB-108/124	1.0	4.0	0.1	0.4	0.1	0.4
PCB-109/119/86/97/125/87	1.0	4.0	0.1	0.4	0.1	0.4
PCB-107	1.0	4.0	0.1	0.4	0.1	0.4
PCB-110/115	1.0	4.0	0.1	0.4	0.1	0.4
PCB-111	1.0	4.0	0.1	0.4	0.1	0.4
PCB-112	1.0	4.0	0.1	0.4	0.1	0.4
PCB-113/90/101	1.0	4.0	0.1	0.4	0.1	0.4
PCB-114	1.0	4.0	0.1	0.4	0.1	0.4
PCB-117/116/85	1.0	4.0	0.4	2.0	0.1	0.4
PCB-118	1.0	4.0	0.4	2.0	0.1	0.4

Table B-5. Method and RL goals for PCB congeners in water, sediment, and tissue

Analyte	EPA Method 1668C					
	Water (pg/L) Based on 1-L sample		Sediment[c] (ng/kg dw) Based on 10-g sample		Tissue[d] (ng/kg ww) Based on 10-g sample	
	EDL[a]	LMCL[b]	EDL	LMCL	EDL	LMCL
PCB-120	1.0	4.0	0.4	2.0	0.1	0.4
PCB-121	1.0	4.0	0.4	2.0	0.1	0.4
PCB-122	1.0	4.0	0.4	2.0	0.1	0.4
PCB-123	1.0	4.0	0.4	2.0	0.1	0.4
PCB-126	1.0	4.0	0.4	2.0	0.1	0.4
PCB-127	1.0	4.0	0.4	2.0	0.1	0.4
PCB-128/166	1.0	4.0	0.4	2.0	0.1	0.4
PCB-130	1.0	4.0	0.4	2.0	0.1	0.4
PCB-131	1.0	4.0	0.4	2.0	0.1	0.4
PCB-132	1.0	4.0	0.4	2.0	0.1	0.4
PCB-133	1.0	4.0	0.4	2.0	0.1	0.4
PCB-134/143	1.0	4.0	0.4	2.0	0.1	0.4
PCB-136	1.0	4.0	0.4	2.0	0.1	0.4
PCB-137	1.0	4.0	0.4	2.0	0.1	0.4
PCB-138/163/129/160	1.0	4.0	0.4	2.0	0.1	0.4
PCB-139/140	1.0	4.0	0.4	2.0	0.1	0.4
PCB-141	1.0	4.0	0.4	2.0	0.1	0.4
PCB-142	1.0	4.0	0.4	2.0	0.1	0.4
PCB-144	1.0	4.0	0.4	2.0	0.1	0.4
PCB-145	1.0	4.0	0.4	2.0	0.1	0.4
PCB-146	1.0	4.0	0.4	2.0	0.1	0.4
PCB-147/149	1.0	4.0	0.4	2.0	0.1	0.4
PCB-148	1.0	4.0	0.4	2.0	0.1	0.4
PCB-150	1.0	4.0	0.4	2.0	0.1	0.4
PCB-151/135/154	1.0	4.0	0.4	2.0	0.1	0.4
PCB-152	1.0	4.0	0.4	2.0	0.1	0.4
PCB-153/168	1.0	4.0	0.4	2.0	0.1	0.4
PCB-155	1.0	4.0	0.4	2.0	0.1	0.4
PCB-156/157	1.0	4.0	0.4	4.0	0.1	0.4
PCB-158	1.0	4.0	0.4	2.0	0.1	0.4
PCB-159	1.0	4.0	0.4	2.0	0.1	0.4
PCB-161	1.0	4.0	0.1	0.4	0.1	0.4
PCB-162	1.0	4.0	0.1	0.4	0.1	0.4

Table B-5. Method and RL goals for PCB congeners in water, sediment, and tissue

Analyte	EPA Method 1668C					
	Water (pg/L) Based on 1-L sample		Sediment[c] (ng/kg dw) Based on 10-g sample		Tissue[d] (ng/kg ww) Based on 10-g sample	
	EDL[a]	LMCL[b]	EDL	LMCL	EDL	LMCL
PCB-164	1.0	4.0	0.1	0.4	0.1	0.4
PCB-165	1.0	4.0	0.1	0.4	0.1	0.4
PCB-167	1.0	4.0	0.1	0.4	0.1	0.4
PCB-169	1.0	4.0	0.1	0.4	0.1	0.4
PCB-170	1.0	4.0	0.1	0.4	0.1	0.4
PCB-171/173	1.0	4.0	0.1	0.4	0.1	0.4
PCB-172	1.0	4.0	0.1	0.4	0.1	0.4
PCB-174	1.0	4.0	0.1	0.4	0.1	0.4
PCB-175	1.0	4.0	0.1	0.4	0.1	0.4
PCB-176	1.0	4.0	0.1	0.4	0.1	0.4
PCB-177	1.0	4.0	0.1	0.4	0.1	0.4
PCB-178	1.0	4.0	0.1	0.4	0.1	0.4
PCB-179	1.0	4.0	0.1	0.4	0.1	0.4
PCB-180/193	1.0	4.0	0.1	0.4	0.1	0.4
PCB-181	1.0	4.0	0.1	0.4	0.1	0.4
PCB-182	1.0	4.0	0.1	0.4	0.1	0.4
PCB-183/185	1.0	4.0	0.1	0.4	0.1	0.4
PCB-184	1.0	4.0	0.1	0.4	0.1	0.4
PCB-186	1.0	4.0	0.1	0.4	0.1	0.4
PCB-187	1.0	4.0	0.1	0.4	0.1	0.4
PCB-188	1.0	4.0	0.1	0.4	0.1	0.4
PCB-189	1.0	4.0	0.1	0.4	0.1	0.4
PCB-190	1.0	4.0	0.1	0.4	0.1	0.4
PCB-191	1.0	4.0	0.1	0.4	0.1	0.4
PCB-192	1.0	4.0	0.1	0.4	0.1	0.4
PCB-194	1.0	4.0	0.1	0.4	0.1	0.4
PCB-195	1.0	4.0	0.1	0.4	0.1	0.4
PCB-196	1.0	4.0	0.1	0.4	0.1	0.4
PCB-197/200	1.0	4.0	0.1	0.4	0.1	0.4
PCB-198/199	1.0	4.0	0.1	0.4	0.1	0.4
PCB-201	1.0	4.0	0.1	0.4	0.1	0.4
PCB-202	1.0	4.0	0.1	0.4	0.1	0.4
PCB-203	1.0	4.0	0.1	0.4	0.1	0.4

Table B-5. Method and RL goals for PCB congeners in water, sediment, and tissue

Analyte	EPA Method 1668C					
	Water (pg/L) Based on 1-L sample		Sediment[c] (ng/kg dw) Based on 10-g sample		Tissue[d] (ng/kg ww) Based on 10-g sample	
	EDL[a]	LMCL[b]	EDL	LMCL	EDL	LMCL
PCB-204	1.0	4.0	0.1	0.4	0.1	0.4
PCB-205	1.0	4.0	0.1	0.4	0.1	0.4
PCB-206	1.0	4.0	0.1	0.4	0.1	0.4
PCB-207	1.0	4.0	0.1	0.4	0.1	0.4
PCB-208	1.0	4.0	0.1	0.4	0.1	0.4
PCB-209	1.0	4.0	0.1	0.4	0.1	0.4

[a] EDL is a sample-specific DL. The value provided here is an estimate, and the sample-specific values will vary based on sample mass and the analytical conditions at the time of analysis.

[b] LMCL is Axys's lowest calibration limit. Detected values below the LMCL are J-qualified. The reported LMCL will be adjusted based on the sample mass of each sample.

[c] Sediment cleanup levels for total PCBs in 0- to 10-cm-deep sediments (µg/kg dw) are 2 for RAO 1, 1,300 for RAO 2, and 128 for RAO 4. The sediment cleanup levels for 0- to 45-cm-deep sediments (µg/kg dw) for RAO 2 are 500 in clamming areas and 1,700 at individual beaches.

[d] Target tissue levels for total PCBs (µg/kg ww) are 12 (benthic fish, fillet), 1.8 (pelagic fish, whole body), 1.1 (crab, edible meat), 9.1 (crab, whole body), and 0.42 (clams).

Axys – Axys Analytical Services, Ltd.
DL – detection limit
dw – dry weight
EPA – US Environmental Protection Agency
EDL – estimated detection limit
J – estimated concentration
LMCL – lower method calibration limit
PCB – polychlorinated biphenyl
RAO – remedial action objective
RL – reporting limit
ww – wet weight

Table B-6. Method and RL goals for dioxins/furan congeners in water

Analyte	EPA Method 1613B	
	Water (pg/L)[a] Based on 1-L sample	
	EDL[b]	LMCL[c]
2,3,7,8-TCDD	0.50	2.0
1,2,3,7,8-PeCDD	0.50	10.0
1,2,3,4,7,8-HxCDD	0.50	10.0
1,2,3,6,7,8-HxCDD	0.50	10.0
1,2,3,7,8,9-HxCDD	0.50	10.0
1,2,3,4,6,7,8-HpCDD	0.50	10.0
OCDD	0.50	20.0
2,3,7,8-TCDF	0.50	2.0
1,2,3,7,8-PeCDF	0.50	10.0

Table B-6. Method and RL goals for dioxins/furan congeners in water

Analyte	EPA Method 1613B	
	Water (pg/L)[a] Based on 1-L sample	
	EDL[b]	LMCL[c]
2,3,4,7,8-PeCDF	0.50	10.0
1,2,3,4,7,8-HxCDF	0.50	10.0
1,2,3,6,7,8-HxCDF	0.50	10.0
1,2,3,7,8,9-HxCDF	0.50	10.0
2,3,4,6,7,8-HxCDF	0.50	10.0
1,2,3,4,6,7,8-HpCDF	0.50	10.0
1,2,3,4,7,8,9-HpCDF	0.50	10.0
OCDF	0.50	20.0

[a] The national recommended AWQC human health criteria for consumption of organism only is 0.0051 pg/L and the Washington State criteria is 0.014 pg/L.

[b] EDL is a sample-specific DL. The value provided here is an estimate, and the sample-specific values will vary based on sample mass and the analytical conditions at the time of analysis

[c] LMCL is Axys's lowest calibration limit. Detected values below the LMCL are J-qualified. The reported LMCL will be adjusted based on the sample mass of each sample.

Axys – Axys Analytical Services, Ltd.
DL – detection limit
EPA – US Environmental Protection Agency
EDL – estimated detection limit
HpCDD – heptachlorodibenzo-p-dioxin
HpCDF – heptachlorodibenzofuran
HxCDD – hexachlorodibenzo-p-dioxin
HxCDF – hexachlorodibenzofuran
LMCL – lower method calibration limit
OCDD – octachlorodibenzo-p-dioxin
OCDF – octachlorodibenzofuran
PeCDD – pentachlorodibenzo-p-dioxin
PeCDF – pentachlorodibenzofuran
RL – reporting limit
TCDD – tetrachlorodibenzo-p-dioxin
TCDF – tetrachlorodibenzofuran
TEQ – toxic equivalent

Table B-7. Method and RL goals for dioxins/furan congeners in sediment and tissue

Analyte	EPA Method 1613B					
	Sediment[a] (ng/kg dw) Based on 10-g sample		Tissue[b] (ng/kg ww) Based on 10-g sample		TEQ (ng/kg)	
	EDL[c]	LMCL[d]	EDL[c]	LMCL[d]	TEF	TEQ[e]
2,3,7,8-TCDD	0.05	0.2	0.05	0.20	1	0.025
1,2,3,7,8-PeCDD	0.05	1.0	0.05	1.00	1	0.025
1,2,3,4,7,8-HxCDD	0.05	1.0	0.05	1.00	0.1	0.0025
1,2,3,6,7,8-HxCDD	0.05	1.0	0.05	1.00	0.1	0.0025
1,2,3,7,8,9-HxCDD	0.05	1.0	0.05	1.00	0.1	0.0025

Table B-7. Method and RL goals for dioxins/furan congeners in sediment and tissue

Analyte	EPA Method 1613B					
	Sediment[a] (ng/kg dw) Based on 10-g sample		Tissue[b] (ng/kg ww) Based on 10-g sample		TEQ (ng/kg)	
	EDL[c]	LMCL[d]	EDL[c]	LMCL[d]	TEF	TEQ[e]
1,2,3,4,6,7,8-HpCDD	0.05	1.0	0.05	1.00	0.01	0.00025
OCDD	0.05	2.0	0.05	2.00	0.0003	0.0000075
2,3,7,8-TCDF	0.05	0.2	0.05	0.20	0.1	0.0025
1,2,3,7,8-PeCDF	0.05	1.0	0.05	1.00	0.03	0.00075
2,3,4,7,8-PeCDF	0.05	1.0	0.05	1.00	0.3	0.0075
1,2,3,4,7,8-HxCDF	0.05	1.0	0.05	1.00	0.1	0.0025
1,2,3,6,7,8-HxCDF	0.05	1.0	0.05	1.00	0.1	0.0025
1,2,3,7,8,9-HxCDF	0.05	1.0	0.05	1.00	0.1	0.0025
2,3,4,6,7,8-HxCDF	0.05	1.0	0.05	1.00	0.1	0.0025
1,2,3,4,6,7,8-HpCDF	0.05	1.0	0.05	1.00	0.01	0.00025
1,2,3,4,7,8,9-HpCDF	0.05	1.0	0.05	1.00	0.01	0.00025
OCDF	0.05	2.0	0.05	2.00	0.0003	0.0000075

[a] Sediment cleanup levels for dioxin/furan congeners in 0- to 10-cm-deep sediments (ng TEQ/kg dw) are 2 for RAO 1 and 37 for RAO 2. The sediment cleanup levels for 0- to 45-cm-deep sediments (ng TEQ/kg dw) for RAO 2 are 13 in clamming areas and 28 at individual beaches. The TEQ RL goal for dioxins/furans in sediments is 1.14 ng/TEQ/kg dw.

[b] Target tissue levels for dioxin/furan TEQ (ng/kg ww) are 0.35 (benthic fish, whole body), 0.53 (crab, edible meat), 2.0 (crab, whole body), and 0.71 (clams). The TEQ RL goal for 2,3,7,8-TCDD in tissues is 0.1 ng/TEQ/kg ww.

[c] EDL is a sample-specific DL. The value provided here is an estimate, and the sample-specific values will vary based on sample mass and the analytical conditions at the time of analysis

[d] LMCL is Axys's lowest calibration limit. Detected values below the LMCL are J-qualified. The reported LMCL will be adjusted based on the sample mass of each sample.

[e] TEQ calculated using ½ RL value multiplied by the TEF

Axys – Axys Analytical Services, Ltd.
DL – detection limit
dw – dry weight
EPA – US Environmental Protection Agency
EDL – estimated detection limit
HpCDD – heptachlorodibenzo-p-dioxin
HpCDF – heptachlorodibenzofuran
HxCDD – hexachlorodibenzo-p-dioxin
HxCDF – hexachlorodibenzofuran
LMCL – lower method calibration limit
OCDD – octachlorodibenzo-p-dioxin
OCDF – octachlorodibenzofuran
PeCDD – pentachlorodibenzo-p-dioxin
PeCDF – pentachlorodibenzofuran
RAO – remedial action objective
RL – reporting limit
TCDD – tetrachlorodibenzo-p-dioxin
TCDF – tetrachlorodibenzofuran
TEF – toxic equivalency factor
TEQ – toxic equivalent
ww – wet weight

Table B-8. Surface water analytes, analytical methods, MDLs, RLs, and WQC

Analyte	Method	Unit	MDL	RL	National Recommended AWQC			Washington State Criteria[a]		
					Aquatic Life		Human Health	Aquatic Life		Human Health
					Marine		Consumption of Organism Only	Marine		Consumption of Organism Only
					CMC (Acute)	CCC (Chronic)		Acute	Chronic	
Metals and organometals										
Antimony	EPA 1638	µg/L	0.1	0.3	–	–	640	–	–	90
Arsenic	EPA 1638	µg/L	0.07	0.4	69[b]	36[b]		69[b]	36[b]	
Inorganic arsenic	EPA 1632	µg/L	0.008	0.025			0.14			0.14
Cadmium	EPA 1638	µg/L	0.04	0.12	33[b]	7.9[b]	–	42[b]	9.3[b]	–
Chromium	EPA 1638	µg/L	0.25	0.75	–	–	–	–	–	–
Chromium III[c]	na	µg/L	–	–	–	–	–	–	–	–
Chromium VI[c]	na	µg/L	–	–	1,100[b]	50[b]	–	1,100[b]	50[b]	–
Copper	EPA 1638	µg/L	0.22	0.66	4.8[b]	3.1[b]	–	4.8[b]	3.1[b]	–
Lead	EPA 1638	µg/L	0.05	0.15	210[b]	8.1[b]	–	210.0[b]	8.1[b]	–
Mercury[d]	EPA 1631E	µg/L	0.0001	0.0004	1.8[b]	0.94[b]	–	1.8[b]	0.025	–
Methylmercury[c, d]	na	µg/L	0.000020	0.00005	1.8[b]	0.94[b]	0.3[d]	–	–	–
Nickel	EPA 1638	µg/L	0.23	0.69	74[b]	8.2[b]	4,600	74.0[b]	8.2[b]	100
Selenium	EPA 1638	µg/L	0.11	0.4	290[b]	71[b]	4,200	290[b]	71.0[b]	200
Silver	EPA 1638	µg/L	0.06	0.18	1.9[b]	–	–	1.9[b]	–	–
Thallium	EPA 1638	µg/L	0.13	**0.4**	–	–	0.47	–	–	0.27
Zinc	EPA 1638	µg/L	1.2	4	90[b]	81[b]	26,000	90[b]	81[b]	1000
TBT	EPA 8270D-SIM	µg/L	TBD[e]	**0.052**	0.42	0.0074	–	–	–	–
PAHs										
Acenaphthene	EPA 8270D-SIM	µg/L	0.00289	0.0100	–	–	90	–	–	30
Anthracene	EPA 8270D-SIM	µg/L	0.00116	0.0100	–	–	400	–	–	100
Benzo(a)anthracene	EPA 8270D-SIM	µg/L	**0.000750**	**0.0100**	–	–	0.0013	–	–	0.00016
Benzo(a)pyrene	EPA 8270D-SIM	µg/L	**0.00248**	**0.0100**	–	–	0.00013	–	–	0.000016
Benzo(b)fluoranthene	EPA 8270D-SIM	µg/L	**0.000460**	**0.0100**	–	–	0.0013	–	–	0.00016
Benzo(k)fluoranthene	EPA 8270D-SIM	µg/L	**0.00321**	**0.0100**	–	–	0.013	–	–	0.0016
Chrysene	EPA 8270D-SIM	µg/L	0.000900	0.0100	–	–	0.13	–	–	0.016
Dibenzo(a,h)anthracene	EPA 8270D-SIM	µg/L	**0.00134**	**0.0100**	–	–	0.00013	–	–	0.000016
Fluoranthene	EPA 8270D-SIM	µg/L	0.00171	0.0100	–	–	20	–	–	6
Fluorene	EPA 8270D-SIM	µg/L	0.00152	0.0100	–	–	70	–	–	10
Indeno(1,2,3-cd)pyrene	EPA 8270D-SIM	µg/L	**0.00101**	**0.0100**	–	–	0.0013	–	–	0.00016
Pyrene	EPA 8270D-SIM	µg/L	0.00118	0.0100	–	–	30	–	–	8
Phthalates										
Bis(2-ethylhexyl)phthalate	EPA 8270D	µg/L	**0.345**[f]	**3.00**[g]	–	–	0.37	–	–	0.046

Table B-8. Surface water analytes, analytical methods, MDLs, RLs, and WQC

Analyte	Method	Unit	MDL	RL	National Recommended AWQC			Washington State Criteria[a]		
					Aquatic Life		Human Health	Aquatic Life		Human Health
					Marine			Marine		
					CMC (Acute)	CCC (Chronic)	Consumption of Organism Only	Acute	Chronic	Consumption of Organism Only
Butyl benzyl phthalate	EPA 8270D	µg/L	**0.320**[f]	**1.00**[g]	–	–	0.10	–	–	0.013
Diethyl phthalate	EPA 8270D	µg/L	0.292[f]	1.00[g]	–	–	600	–	–	200
Dimethyl phthalate	EPA 8270D	µg/L	0.362[f]	1.00[g]	–	–	2,000	–	–	600
Di-n-butyl phthalate	EPA 8270D	µg/L	0.336[f]	1.00[g]	–	–	30	–	–	8
Other SVOCs										
1,2,4,5-Tetrachloro-benzene	EPA 8270D	µg/L	TBD[e,f]	**1.00**[g]	–	–	0.03	–	–	–
1,2-Diphenylhydrazine	EPA 8270D	µg/L	**0.269**[f]	**1.00**[g]	–	–	0.2	–	–	0.02
2,4,5-Trichlorophenol	EPA 8270D	µg/L	1.03[f]	5.00[g]	–	–	600	–	–	–
2,4,6-Trichlorophenol	EPA 8270D	µg/L	**0.934**[f]	**3.00**[g]	–	–	2.8	–	–	0.28
2,4-Dichlorophenol	EPA 8270D	µg/L	0.816[f]	3.00[g]	–	–	60	–	–	10
2,4-Dimethylphenol	EPA 8270D	µg/L	0.350[f]	3.00[g]	–	–	3,000	–	–	97
2,4-Dinitrophenol	EPA 8270D	µg/L	4.25[f]	20.0[g]	–	–	300	–	–	100
2,4-Dinitrotoluene	EPA 8270D	µg/L	**1.18**[f]	**3.00**[g]	–	–	1.7	–	–	0.18
2-Chloronaphthalene	EPA 8270D	µg/L	0.302[f]	1.0[g]	–	–	1000	–	–	100
2-Chlorophenol	EPA 8270D	µg/L	0.276[f]	1.0[g]	–	–	800	–	–	17
3,3'-Dichlorobenzidine	EPA 8270D	µg/L	**1.57**[f]	**5.00**[g]	–	–	0.15	–	–	0.0033
4,6-Dinitro-o-cresol	EPA 8270D	µg/L	3.41[f]	**10.0**[g]	–	–	30	–	–	7
4-Chloro-3-methylphenol	EPA 8270D	µg/L	1.00[f]	3.00[g]	–	–	2,000	–	–	36
Benzidine	EPA 8270D	µg/L	**5.00**[f]	**10.0**[g]	–	–	0.011	–	–	0.000023
bis(2-chloroethyl)ether	EPA 8270D	µg/L	**0.235**[f]	**1.00**[g]	–	–	2.2	–	–	0.06
bis(2-chloroisopropyl)ether	EPA 8270D	µg/L	0.191[f]	1.00[g]	–	–	4,000	–	–	900
bis(chloromethyl) ether	EPA 8270D	µg/L	TBD[e,f]	**1.00**[g,h]	–	–	0.017	–	–	–
Hexachlorobenzene	EPA 8270D	µg/L	**0.333**[f]	**1.00**[g]	–	–	0.000079	–	–	0.0000050
Hexachloroethane	EPA 8270D	µg/L	**0.244**[f]	**2.00**[g]	–	–	0.1	–	–	0.02
Hexachlorocyclopentadiene	EPA 8270D	µg/L	**1.49**[f]	**5.00**[g]	–	–	4	–	–	1
Isophorone	EPA 8270D	µg/L	0.222[f]	1.00[g]	–	–	1,800	–	–	110
n-Nitrosodiethylamine	EPA 8270D	µg/L	TBD[e,f]	1.00[g,h]	–	–	1.24	–	–	–
n-Nitrosodimethylamine	EPA 8270D	µg/L	**0.935**[f]	**3.00**[g]	–	–	3	–	–	0.34
n-Nitroso-di-n-butylamine	EPA 8270D	µg/L	TBD[e,f]	**1.00**[g,h]	–	–	0.22	–	–	–
n-Nitroso-di-n-propylamine	EPA 8270D	µg/L	**0.296**[f]	**1.0**[g]	–	–	0.51	–	–	0.058
n-Nitrosodiphenylamine	EPA 8270D	µg/L	0.252[f]	**1.00**[g]	–	–	6	–	–	0.69
n-Nitrosopyrrolidine	EPA 8270D	µg/L	TBD[e,f]	1.00[g,h]	–	–	34	–	–	–
Nitrobenzene	EPA 8270D	µg/L	0.202[f]	1.00[g]	–	–	600	–	–	100

Table B-8. Surface water analytes, analytical methods, MDLs, RLs, and WQC

Analyte	Method	Unit	MDL	RL	National Recommended AWQC			Washington State Criteria[a]		
					Aquatic Life		Human Health	Aquatic Life		Human Health
					Marine		Consumption of Organism Only	Marine		Consumption of Organism Only
					CMC (Acute)	CCC (Chronic)		Acute	Chronic	
Nonylphenol (mixed isomers)	EPA 8270D	µg/L	TBD[e,f]	1.00[g,h]	7	1.7	–	–	–	–
Pentachlorobenzene	EPA 8270D	µg/L	TBD[e,f]	**1.00**[g,h]	–	–	0.1	–	–	–
Pentachlorophenol	EPA 8270D	µg/L	**1.58**[f]	**10.0**[g]	13	7.9	0.04	13	7.9	0.002
Phenol	EPA 8270D	µg/L	0.154[f]	1.00[g]	–	–	300,000	–	–	70,000
Total dinitrophenols	EPA 8270D	µg/L	TBD[e,f]	3.0[g,h]	–	–	1000	–	–	–
Total nitrosamines	EPA 8270D	µg/L	**0.935**[f]	**3.0**[g]	–	–	1.24	–	–	–
PCBs										
Total PCB (congeners)	EPA 1668C	µg/L	0.000001[i]	0.000004[j]	–	0.03	0.000064	10.0	0.030	0.000007
Dioxins/furans										
2,3,7,8-TCDD	EPA 1613B	pg/L	**0.62**	**2.0**	–	–	0.0051	–	–	0.014
Pesticides										
4,4'-DDD	EPA 8081B	µg/L	**0.0186**[f]	**0.0500**[g]	–	–	0.00012	–	–	0.0000079
4,4'-DDE	EPA 8081B	µg/L	**0.0184**[f]	**0.0500**[g]	–	–	0.000018	–	–	0.00000088
4,4'-DDT	EPA 8081B	µg/L	**0.0169**[f]	**0.0500**[g]	0.13	0.001	0.00003	0.13	0.001	0.0000012
Aldrin	EPA 8081B	µg/L	**0.0103**[f]	**0.0250**[g]	1.3		0.00000077	0.71[k]	0.0019[k]	0.000000041
Dieldrin	EPA 8081B	µg/L	**0.0168**[f]	**0.0500**[g]	0.71	0.0019	0.0000012	0.71[k]	0.0019[k]	0.000000070
alpha-BHC	EPA 8081B	µg/L	**0.00850**[f]	**0.0250**[g]	–	–	0.00039	–	–	0.000048
beta-BHC	EPA 8081B	µg/L	0.00980[f]	**0.0250**[g]	–	–	0.014	–	–	0.0014
gamma-BHC	EPA 8081B	µg/L	0.0159[f]	0.0250[g]	0.16	–	4.4	0.16		0.43
Total chlordane	EPA 8081B	µg/L	**0.00950**[f]	**0.050**[g]	0.09	0.004	0.00032	0.09	0.004	0.000022
alpha-Endosulfan	EPA 8081B	µg/L	**0.00890**[f]	**0.0250**[g]	0.034[l]	0.0087[l]	30	0.034[l]	0.0087[l]	7
beta-Endosulfan	EPA 8081B	µg/L	**0.0139**[f]	**0.0250**[g]	0.034[l]	0.0087[l]	40	0.034[l]	0.0087[l]	10
Endosulfan sulfate	EPA 8081B	µg/L	0.0235[f]	0.0500[g]	–	–	40	–	–	10
Endrin	EPA 8081B	µg/L	**0.0167**[f]	**0.0500**[g]	0.037	0.0023	0.03	0.037	0.0023	0.002
Endrin aldehyde	EPA 8081B	µg/L	0.0163[f]	**0.0500**[g]	–	–	1	–	–	0.035
Heptachlor	EPA 8081B	µg/L	**0.0113**[f]	**0.0250**[g]	0.053	0.0036	0.0000059	0.053	0.0036	0.00000034
Heptachlor epoxide	EPA 8081B	µg/L	**0.00790**[f]	**0.0500**[g]	0.053	0.0036	0.000032	–	–	0.0000024
Hexachlorocyclohexane-G	EPA 8081B	µg/L	TBD[e,f]	**1.00**[g,h]	–	–	0.010	–	–	–
Methoxychlor	EPA 8081B	µg/L	**0.0744**[f]	**0.250**[g]	–	0.03	0.02	–	–	–
Mirex	EPA 8081B	µg/L	**0.0104**[f]	**0.0500**[g]	–	0.001	–	–	–	–
Toxaphene	EPA 8081B	µg/L	**0.220**[f]	**1.25**[g]	0.21	0.0002	0.00071	0.21	0.0002	0.000032

Table B-8. Surface water analytes, analytical methods, MDLs, RLs, and WQC

Analyte	Method	Unit	MDL	RL	National Recommended AWQC			Washington State Criteria[a]		
					Aquatic Life		Human Health	Aquatic Life		Human Health
					Marine		Consumption of Organism Only	Marine		Consumption of Organism Only
					CMC (Acute)	CCC (Chronic)		Acute	Chronic	
Pesticide- Carbamate										
Carbaryl	EPA 8321	µg/L	0.004	0.02	1.6	–	–	–	–	–
Pesticides - organophosphorus										
Chlorpyrifos	EPA 8141B	µg/L	**0.036**	**0.2**	0.011	0.0056	–	0.011	0.0056	–
Diazinon	EPA 8141B	µg/L	0.051	0.2	0.82	0.82	–	–	–	–
Malathion	EPA 8141B	µg/L	0.076	0.2	–	0.1	–	–	–	–

Bold underlined reporting limits and method detection limits are greater than the lowest criteria value.

[a] Washington State criteria listed include standards promulgated in WAC 173-201A and human health criteria consistent with the Washington Toxics Rule (40 CFR 131.45 as applied to Washington), and 40 CFR 131.36(d)(14), including the 40 CFR 131 criteria updated on November 28, 2016. The ARAR is the most stringent of these water quality criteria. Values listed have been updated since the publication of the ROD.

[b] Criteria applied to dissolved fraction.

[c] Total value will be compared to criterion for related chemical species.

[d] Methylmercury criterion is expressed as fish tissue concentration (mg/kg). *Water Quality Criterion for the Protection of Human Health: Methyl Mercury (*EPA-823-R-01-001) contains information for how the value is calculated using the criterion in EPA's 2000 Human Health Methodology.

[e] Laboratory to perform MDL study prior to analysis.

[f] SW846 no longer requires MDL values. The laboratories have the option to use these values to assess sensitivity for EPA 8000 series methods. ARI has continued to maintain MDL studies for these analytes.

[g] RL values are consistent with the LLOQ values required under EPA SW846.

[h] Estimated RL; laboratory will confirm RL prior to analysis.

[i] EDL is a sample-specific DL. The value provided here is an estimate, and the sample-specific values will vary based on sample mass and the analytical conditions at the time of analysis.

[j] Value represents laboratory-specific LMCL value for an individual PCB congener based on a 1-L sample.

[k] Criteria for sum of aldrin and dieldrin.

[l] Criteria for sum of alpha-Endosulfan and beta-Endosulfan.

ARAR – applicable or relevant and appropriate requirement
AWQC – ambient water quality criteria
BHC – benzene hexachloride
CCC – criterion continuous concentration
CFR – Code of Federal Regulations
CMC – criterion maximum concentrations
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
EPA – US Environmental Protection Agency
EDL – estimated detection limit
LMCL – lower method calibration limit
MDL – method detection limit
na – not applicable
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RL – reporting limit
SIM – selective ion monitoring
SVOC – semivolatile organic compound
TBD – to be determined via MDL study
TBT – tributyltin
TCDD – tetrachlorodibenzo-*p*-dioxin
WAC – Washington Administrative Code
WQC – water quality criteria

APPENDIX C. DATA MANAGEMENT PLAN

Table of Contents

Tables

Acronyms

AET	apparent effects threshold
AOC	Administrative Order on Consent
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSL	cleanup screening level
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
EPA	US Environmental Protection Agency
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HpCDD	heptachlorodibenzo-*p*-dioxin
HpCDF	heptachlorodibenzofuran
HxCDD	hexachlorodibenzo-*p*-dioxin
HxCDF	hexachlorodibenzofuran
LAET	lowest apparent effects threshold
LDW	Lower Duwamish Waterway
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
OCDD	octachlorodibenzo-*p*-dioxin
OCDF	octachlorodibenzofuran
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PeCDD	pentachlorodibenzo-*p*-dioxin
PeCDF	pentachlorodibenzofuran
PEF	potency equivalency factor
QC	quality control
RI/FS	remedial investigation / feasibility study
RL	reporting limit
SCO	sediment cleanup objective
SIM	selected ion monitoring
SMS	Washington State Sediment Management Standards
SQS	sediment quality standards

SVOC	semivolatile organic compound
TCDD	tetrachlorodibenzo-*p*-dioxin
TCDF	tetrachlorodibenzofuran
TEF	toxic equivalency factor
TEQ	toxic equivalent
TOC	total organic carbon
WAC	Washington Administrative Code
WHO	World Health Organization

1 Introduction

This appendix presents the data management plan for the pre-design studies project. It contains two main sections:

- Section 2. Project database structure and data usability
- Section 3. Data management rules

2 Project Database Structure and Data Usability

The project database published with the Lower Duwamish Waterway (LDW) remedial investigation / feasibility study (RI / FS) is a Microsoft Access® database containing sediment, water, and tissue chemistry data for samples collected between 1990 and 2010. This section describes planned revisions to the project database structure; the incorporation of new in-waterway, upstream, and source control-related data compiled under Task 2;[1] and the process for future data additions.

2.1 Project Database Structure Revisions

The existing project database stores the RI / FS chemistry data in six media-specific tables: surface sediment, subsurface sediment, tissue, surface water, porewater, and seeps. In order to simplify usage and management of these data, the existing six tables will be consolidated into three tables containing in-waterway data of similar media types: sediment chemistry, tissue chemistry, and water chemistry.

The surface sediment and porewater tables in the existing project database are provided in two forms: one that includes field replicates as discrete samples ("sample-averaged"), and one that provides the average concentration of the parent and field replicate sample for each chemical ("location-averaged"). In order to reduce redundancy and simplify usage of these data, the updated database will present all data on a sample-averaged basis, with field replicates included as discrete samples and clearly identified.

2.2 Incorporation of Task 2 Data

The data compiled under Task 2 includes in-waterway, upstream, and source control-related samples collected between 2010 and 2016. These in-waterway data will be incorporated into the sediment, tissue, and water tables, as described in Section 2.1. The upstream and source control-related data will be added to the project database as five new tables: storm drain and combined sewer system source tracing solids, bank soils, groundwater, upstream surface water, and upstream suspended solids.

[1] Task 2 of the pre-design studies outlined in the third amendment to the Administrative Order on Consent (AOC) (EPA 2016).

2.3 DATA ADDITIONS

Chemistry data from each pre-design study sampling event will be incorporated into the project database following receipt of validated data. In addition, as appropriate, additional in-waterway data unrelated to the pre-design studies will be added as they are made available.

New data will be incorporated into the media-specific tables described in Sections 2.1 and 2.2. Prior to incorporating these data into the database, the new data will be assessed for quality and usability using the data quality review process described in the Task 2 data compilation memo (Windward and Integral 2017).

Additions and revisions to the project database will be documented in a change log table within the Microsoft Access® database. A list of all data additions following the Task 2 compilation will be included in Task 6, the data evaluation report. A final version of the Microsoft Access® project database will be submitted to the US Environmental Protection Agency (EPA) at the end of the project.

2.4 DATA USABILITY

Although the RI/FS and data compiled under Task 2 will be combined for ease of use, these two datasets were originally compiled using different approaches, and the following caveats should be considered during use:

- Preparation of the RI/FS dataset included a spatial and temporal evaluation process that allowed newer data to override older co-located results. This process was conducted for the RI/FS dataset to show the most recent results. No equivalent process was applied to the Task 2 dataset.
- The compilation work for Task 2 specifically excluded pre-cleanup surface and subsurface sediment data from areas that have been dredged or otherwise remediated, so the dataset does not represent all in-waterway data collected between 2010 and 2016.
- The updated in-waterway sediment table will provide a comparison to current Washington State Sediment Management Standards (SMS) criteria, as appropriate. These criteria have been revised since the RI/FS dataset was originally published,[2] so the screening outcomes will not match those previously reported.
- In the RI/FS surface sediment dataset, a single averaged concentration was reported for each chemical at locations that had a field replicate sample. In merged RI/FS and Task 2 datasets for sediment, both parent and field replicate

[2] Some dry weight apparent effects thresholds (AETs) have changed, as well as the total organic carbon (TOC) threshold for carbon normalization.

results for each location will be provided; maps will present the parent sample result instead of an average.

These data usability considerations will be noted in a reference table in the project database, and the data source for each sample (e.g. RI/FS, Task 2) will be clearly identified in each of the chemistry tables.

3 Data Management Rules

Data management rules being followed for the pre-design studies are the same as those applied to the RI/FS dataset, except as noted in this section. Rules summarized in this appendix include those for averaging duplicate or replicate samples (Section 3.1), selecting the preferred result if more than one result is reported for a chemical (Section 3.2), handling significant figures and rounding (Section 3.3), calculating totals when results are summed for individual components (Section 3.4), calculating toxic equivalents (TEQs) for polychlorinated biphenyl (PCB) congeners and dioxin/furan congeners (Sections 3.5 and 3.6, respectively), and calculating carcinogenic polycyclic aromatic hydrocarbons (cPAHs) (Section 3.7).

3.1 Averaging Laboratory Duplicate or Replicate Samples

Contaminant concentrations obtained from the analysis of laboratory duplicates or replicates (i.e., two or more analyses on the same sample) will be averaged for a closer representation of the "true" concentration than that provided by the results of a single analysis. Averaging rules will be dependent on whether the individual results are detected concentrations or reporting limits (RLs) for non-detected analytes. If all concentrations are detected for a given parameter, the values will be simply averaged arithmetically. If all concentrations are non-detected for a given parameter, the minimum RL will be reported. If the concentrations are a mixture of detected concentrations and RLs, any two or more detected concentrations will be averaged arithmetically, and RLs will be ignored. If there is one detected concentration and one or more RLs, the detected concentration will be reported. The latter two rules will be applied regardless of whether the RLs are higher or lower than the detected concentration.

3.2 Selection of Preferred Results

In some instances, the laboratory will generate more than one result for a chemical for a given sample. Multiple results can occur for several reasons, including:

- The original result does not meet the laboratory's internal quality control (QC) guidelines, and a reanalysis is performed.
- The original result does not meet other project data quality objectives, such as a sufficiently low RL, and a reanalysis is performed.

- Two different analytical methods are used for that chemical.

In each case, a single result will be selected for use. The procedures for selecting the preferred result will differ depending on whether a single or multiple analytical methods are used for that chemical.

For the same analytical method, the results will be selected using the following guidance:

- If the results are detected and not qualified, then the result from the lowest dilution will be selected, unless multiple results from the same dilution are available, in which case the result with the highest concentration will be selected.
- If the results are a combination of estimated and unqualified detected results, then the unqualified result will be selected. This situation most commonly occurs when the original result is outside of the calibration range, thus requiring a dilution. The diluted result within the calibration range will be preferentially selected.
- If the results are all estimated, then the result will be selected using best professional judgment and considering the rationale for qualification. For example, a result qualified based on laboratory replicate results outside of QC objectives for precision will be preferred to a qualified result that is outside the calibration range.
- If the results are a combination of detected and non-detected results, then the detected result will be selected. If there are more than one detected result, the applicable rules for multiple results (as discussed above) will be followed.
- If the results are all non-detected, then the lowest RL will be selected.

For different analytical methods (i.e., when a specific chemical is analyzed in the same sample using different methods), the following rules will be applied:

- For results analyzed using the semivolatile organic compound (SVOC) full-scan (EPA 8270) and selected ion monitoring (SIM) (EPA 8270-SIM) methods, the SIM results will be selected.
- For results analyzed using EPA Method 8081A and any 8270 method (i.e., hexachlorobenzene and hexachlorocyclopentadiene), the 8081A result will be selected.

The RI/FS database rules for the selection of preferred results between two methods (as described above) are revised for the compilation of the pre-design data. In the RI/FS, the preferred result was selected based on a comparison between the methods of the detection status, RL, and data qualifiers. The revised rules select the preferred result based on a preference for method.

3.3 SIGNIFICANT FIGURES AND ROUNDING

The analytical laboratories report results with various numbers of significant figures depending on the instrument, parameter, and concentration relative to the RL. The reported (or assessed) precision of each observation will be explicitly stored in the project database as a record of the number of significant figures assigned by the laboratory. The tracking of significant figures will become important when calculating averages and performing other data summaries.

When a calculation involves addition, such as totaling PCBs or polycyclic aromatic hydrocarbons (PAHs), the calculation will be only as precise as the least precise number that goes into the calculation. For example (assuming two significant figures):

> 210 + 19 = 229 will be reported as 230 because 19 is only reported to 2 significant digits, and the enhanced precision of the trailing 0 in the number 210 is not significant.

When a calculation involves multiplication or division, such as carbon normalization, the original figures for each value are carried through the calculation (i.e., individual values are not adjusted to a standard number of significant figures; instead, the appropriate adjustment is made to the resultant value at the end of the calculation). The result is rounded at the end of the calculation to reflect the value with the fewest significant figures used in the calculation. For example:

> 59.9 x 1.2 = 71.88 will be reported as 72 because there are 2 significant figures in the number 1.2.

When rounding, if the number following the last significant figure is less than 5, the digit will be left unchanged. If the number following the last significant figure is equal to or greater than 5, the digit will be increased by 1.

3.4 CALCULATING TOTALS

Total PCBs, total dichlorodiphenyltrichloroethanes (DDTs), total PAHs, total chlordane, total xylenes, and total nitrosamines will be calculated by summing the detected values for the individual components (e.g., Aroclor mixtures or individual congeners for total PCBs). For samples in which none of the individual components are detected, the total value will be given as the highest RL of any individual component, and assigned a U-qualifier (no detected concentrations). No sum will be calculated in cases where 50% or less of the components are analytes. Concentrations for analyte sums will be calculated using the following components:

- Total PCBs will be calculated, in accordance with the methods of the SMS, using only detected values for all Aroclor mixtures. For individual samples in which none of the Aroclor mixtures are detected, total PCBs will be given a value equal to the highest RL of the Aroclors and assigned a U-qualifier (no detected concentrations).

- Total low-molecular-weight PAHs (LPAHs), high-molecular-weight PAHs (HPAHs), PAHs, and benzofluoranthenes will also be calculated in accordance with the methods of the SMS. Total LPAHs will be the sum of detected concentrations for naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene. Total HPAHs were the sum of detected concentrations for fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3,-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. Total benzofluoranthenes will be the sum of the b (i.e., benzo(b)fluoranthene), j, and k isomers.

  Because the j isomer is rarely quantified, the total benzofluoranthenes sum will be typically calculated with only the b and k isomers. In cases where the laboratory provides total benzofluoranthenes instead of or in addition to the b and k isomers, the laboratory result will be reported, and no sum will be calculated. For samples in which all individual compounds within any of the three groups described above are non-detected, the highest RL for that sample will represent the sum.

- Total DDTs will be calculated using only detected values for the DDT isomers: 2,4′-dichlorodiphenyldichloroethane (DDD); 4,4′-DDD; 2,4′-dichlorodiphenyldichloroethylene (DDE); 4,4′-DDE; 2,4′-DDT; and 4,4′-DDT. For individual samples in which none of the isomers are detected, total DDTs will be given a value equal to the highest RL of the six isomers and assigned a U-qualifier (no detected concentrations).

- Total chlordane will be calculated using only detected values for the following compounds: alpha-chlordane, gamma-chlordane, oxychlordane, cis-nonachlor, and trans-nonachlor. For individual samples in which none of these compounds are detected, total chlordane will be given a value equal to the highest RL of the five compounds listed and assigned a U-qualifier (no detected concentrations).

- Total xylene will be calculated using only detected values for m,p-xylene and o-xylene. For individual samples in which neither of these compounds are detected, total xylene will be given a value equal to the higher RL of the two compounds listed and assigned a U-qualifier (no detected concentrations).

- Total nitrosamines will be calculated using only detected values for n-nitrodiethylamine, n-nitrosodimethylamine, n-nitroso-di-n-butylamine, n-nitroso-di-n-propylamine, and n-nitrosodiphenylamine. For individual samples in which none of these compounds are detected, total nitrosamines will be given a value equal to the highest RL of the five compounds listed and assigned a U-qualifier (no detected concentrations).

3.5 CALCULATION OF PCB CONGENER TOXIC EQUIVALENTS

PCB congener TEQs will be calculated using the World Health Organization (WHO) consensus toxic equivalency factor (TEF) values for mammals (Van den Berg et al. 1998; Van den Berg et al. 2006), as presented in Table 1. The TEQ will be calculated as the sum of each PCB congener concentration multiplied by the corresponding TEF value. When the PCB congener concentration is reported as non-detected, then the TEF will be multiplied by one-half the RL.

Table 1. PCB congener TEF values

PCB Congener No.	TEF Value for Mammals (unitless)[a]
77	0.0001
81	0.0003
105	0.00003
114	0.00003
118	0.00003
123	0.00003
126	0.1
156	0.00003
157	0.00003
167	0.00003
169	0.03
189	0.00003

[a] From Van den Berg et al. (2006).
PCB – polychlorinated biphenyl
TEF – toxic equivalency factor

3.6 CALCULATION OF DIOXIN/FURAN CONGENER TEQS

Dioxin/furan congener TEQs will be calculated using the WHO consensus TEF values for mammals (Van den Berg et al. 1998; Van den Berg et al. 2006) as presented in Table 2. The TEQ will be calculated as the sum of each dioxin/furan congener concentration multiplied by the corresponding TEF value. When the dioxin/furan congener concentration is reported as non-detected, then the TEF will be multiplied by one-half the RL.

Table 2. Dioxin/furan congener TEF values

Dioxin/Furan Congener	TEF Value for Mammals (unitless)[a]
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,6,7,8-HpCDD	0.01
1,2,3,4,7,8,9-HpCDF	0.01

Dioxin/Furan Congener	TEF Value for Mammals (unitless)[a]
1,2,3,4,7,8-HxCDF	0.1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,7,8-PeCDF	0.03
1,2,3,7,8-PeCDD	1
2,3,4,6,7,8-HxCDF	0.1
2,3,4,7,8-PeCDF	0.3
2,3,7,8-TCDF	0.1
2,3,7,8-TCDD	1
OCDF	0.0003
OCDD	0.0003

[a] From Van den Berg et al. (2006).

HpCDD – heptachlorodibenzo-*p*-dioxin
HpCDF – heptachlorodibenzofuran
HxCDD – hexachlorodibenzo-*p*-dioxin
HxCDF – hexachlorodibenzofuran
OCDD – octachlorodibenzo-*p*-dioxin
OCDF – octachlorodibenzofuran
PeCDD – pentachlorodibenzo-*p*-dioxin
PeCDF – pentachlorodibenzofuran
TCDD – tetrachlorodibenzo-*p*-dioxin
TCDF – tetrachlorodibenzofuran
TEF – toxic equivalency factor

3.7 CALCULATION OF CARCINOGENIC POLYCYCLIC AROMATIC HYDROCARBONS

cPAH values will be calculated using potency equivalency factor (PEF) values (California EPA 2009) based on the individual PAH component's relative toxicity to benzo(a)pyrene. PEF values are presented in Table 3. The cPAH will be calculated as the sum of each individual PAH concentration multiplied by the corresponding PEF value. When the individual PAH component concentration are reported as non-detected, then the PEF will be multiplied by one-half the RL.

Table 3. cPAH PEF values

cPAH	PEF Value (unitless)[a]
Benzo(a)pyrene	1
Benzo(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.1
Chrysene	0.01
Dibenz(a,h)anthracene	0.4
Indeno(1,2,3-cd)pyrene	0.1

[a] PEFs for cPAHs are defined by California EPA (2009) by dividing the inhalation unit risk factor for the compound by the inhalation unit risk factor for benzo[a]pyrene.

cPAH – carcinogenic polycyclic aromatic hydrocarbon

EPA – US Environmental Protection Agency

PEF – potency equivalency factor

3.8 TOC NORMALIZATION

For comparison to benthic cleanup goals, sediment samples with TOC content < 0.5% or > 3.5% will not be TOC normalized for comparison to the organic carbon-normalized RALs and SMS criteria (Ecology 2015). When TOC normalization is not possible and the dry weight concentration is greater than lowest apparent effects threshold (LAET) and less than or equal to 2LAET, the concentration will be considered to be greater than sediment cleanup objectives (SCOs)[3] and less than or equal to the cleanup screening level (CSL).

[3] SCO, as defined in the 2013 SMS Rule (Washington Administrative Code [WAC] 173-204-562), is equivalent to the term sediment quality standard (SQS) used in the RI/FS (Windward 2010; AECOM 2012).

3.9 CALCULATION OF RECONSTITUTED WHOLE-BODY TISSUE FOR CRAB AND CLAMS

Reconstituted whole-body crab tissue concentrations will be calculated using Equation 1:

$$C_{WB} = (C_{hepatopancreas} \times f_{hepatopancreas}) + (C_{ediblemeat} \times f_{ediblemeat}) \qquad \textbf{Equation 1}$$

Where:

C_{WB} = estimated whole-body tissue concentration (mg/kg ww)

$C_{hepatopancreas}$ = hepatopancreas tissue concentration (mg/kg ww)

$F_{hepatopancreas}$ = average fraction of whole-body weight that is hepatopancreas (average hepatopancreas weight fraction of individual crab that are included in composite sample)

$C_{edible\ meat}$ = edible meat concentration (mg/kg ww)

$F_{edible\ meat}$ = average fraction of whole-body weight that is edible meat (average edible meat fraction of individual crab that are included in composite sample)

Reconstituted whole-body clam tissue concentrations will be calculated using Equation 2:

$$C_{WB} = (C_{siphonskin} \times f_{siphonskin}) + (C_{remainder} \times f_{remainder}) \quad \textbf{Equation 2}$$

Where:

C_{WB} = estimated whole-body tissue concentration (mg/kg ww)

C_{siphon} = siphon skin tissue concentration (mg/kg ww)

F_{siphon} = average fraction of whole-body weight that is siphon skin (average siphon skin weight fraction of individual clams that are included in composite sample)

$C_{remainder}$ = remaining body concentration (mg/kg ww)

$F_{remainder}$ = average fraction of whole-body weight that is the remaining body (average remaining body fraction of individual clams that are included in composite sample)

For reconstituted whole-body concentrations that include a non-detected value for at least one tissue type composite, the non-detected value(s) will be represented in the calculation by one-half the detection limit; the final reconstituted whole-body result will be treated as a detected result. In cases where all tissue type composites are non-detected values, the final reconstituted whole-body result will be assigned a U-qualifier (no detected results), and the weighted sum of the detection limits for the two components will be used to represent the non-detected whole-body concentration.

4 References

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APPENDIX D. SUMMARY OF REMEDIAL DESIGN DATA NEEDS AND TIMING

Table D-1. Summary of remedial design data needs and timing[a]

No.	Data Need	Data Collection Activities	Timing Considerations	2015-2019 ENR/AC Pilot Study	2016-2019 Pre-Design Studies	TBD[b] Remedial Design Investigation[c]	TBD[b] Remedial Design Engineering[c,d]	TBD[b] Remedial Action[e]
Environmental Information								
1	Characterize surface sediment baseline conditions to: · Serve as a baseline for comparison to post-remedial action data. · Evaluate post-RI/FS trends reflecting the combined effects of EAAs, source control progress, and natural recovery processes	Sampling and analysis of COCs in: · Site-wide sediment (0–10 cm) SWAC and 95UCL · Site-wide clamming area intertidal sediment (0–45 cm) mean and 95UCL · Individual beach play areas sediment (0–45 cm) means and 95UCL	After early actions to establish baseline conditions for RAOs 1, 2, and 4		ü			
2	Characterize tissue baseline conditions to: · Serve as a baseline for comparison to post-remedial action data · Evaluate post-RI/FS trends reflecting the combined effects of EAAs, source control progress, and natural recovery processes.	Sampling and analysis of COCs in fish, crab, and clam tissues	2+ years after last early action to establish baseline conditions for tracking progress toward target tissue levels associated with RAO 1		ü			
3	Characterize surface water baseline conditions to: · Serve as a baseline for comparison to post-remedial action data · Evaluate post-RI/FS trends reflecting the combined effects of EAAs, source control progress, and natural recovery processes.	Sampling and analysis of water quality criteria parameters in surface water	After early actions to establish baseline conditions and facilitate assessment of progress toward ARAR compliance		ü			
4	Characterize COCs in sediment (including under-pier areas where appropriate) to support delineation of remedial technology assignment boundaries, definition of dredge prisms and waste characterization, and establishment of baseline conditions for delineated MNR > SCO areas.	Location-specific sampling and analysis of COCs in sediments, including: · Limits of surface (0–10 cm) and subsurface (0–45 or 0–60 cm) RAL exceedances · Subsurface coring to determine dredge prisms and characterize waste · Characterization of surface (0–10 cm) COC trends to support revised estimates of sedimentation and recovery for MNR > SCO areas · Characterization of surface (0–10 cm) COCs to establish baseline conditions for MNR > SCO areas (for RAO3 compliance)	Data must be obtained during design to finalize technology assignments, establish accurate delineation of remedial technology footprints, and design dredge prisms. The remedial design investigation data used to delineate the MNR > SCO areas may be sufficient to serve as the baseline data for compliance monitoring starting in year 0.			ü	if needed	

No.	Data Need	Data Collection Activities	Timing Considerations	2015-2019 ENR/AC Pilot Study	2016-2019 Pre-Design Studies	TBD[b] Remedial Design Investigation[c]	TBD[b] Remedial Design Engineering[c,d]	TBD[b] Remedial Action[e]
5	Characterize sediment porewater concentrations to: · Determine if porewater data improve the ability to assess the relationship between concentrations of arsenic and cPAHs in clam tissue and sediment in order to evaluate the potential effectiveness of the sediment remedy in reducing concentrations of these COCs in clam tissue. · Establish baseline porewater concentrations in MNR and ENR areas.[f]	The porewater addendum to this work plan provides an evaluation of available porewater data, identification of existing data gaps, and a proposed sampling plan for gathering additional data (Windward [in prep]).	Implement prior to remedial action.	ü	ü			
6	Characterize COCs in sediment porewater to support: · ENR with *in situ* treatment (AC) added · Cap design[g]	For *in situ* treatment, ENR/AC pilot study bulk sediment and porewater PCB data For cap design, equilibrium partitioning calculations based on COCs in sediment Area-specific sampling of sediment porewater, if needed for unusual conditions	Decision for carbon amendment addition to ENR will be based on ENR/AC pilot study outcomes. Cap designs are generally based conservatively on equilibrium partitioning unless unique circumstances require porewater data. Porewater data, if needed, should be obtained during design investigation/design engineering phases based on cap limits and design objectives.	ü		ü	ü	
7	Characterize COCs in relevant media to support source control sufficiency determinations	Sampling and analysis of COCs in: · LDW surface sediment near outfalls · Bank soils · Groundwater seeps	Implement early (i.e., pre-design), with supplemental information, as needed, during design.[g]		ü	ü		
Hydrogeological/Geotechnical Information								
8	Characterize groundwater upwelling rates to support cap design.[g]	Typically evaluate using existing hydrogeologic information or modeling to estimate groundwater upwelling velocities for purposes of cap design. Seepage meters may be used if more refined velocity estimates are needed.	Any new data needed should be obtained during design investigations based on cap limits and design objectives.			ü	ü	

No.	Data Need	Data Collection Activities	Timing Considerations	2015-2019 ENR/AC Pilot Study	2016-2019 Pre-Design Studies	TBD[b] Remedial Design Investigation[c]	TBD[b] Remedial Design Engineering[c,d]	TBD[b] Remedial Action[e]
9	Conduct area-specific characterization of sediment geotechnical properties to: · Determine sediment stability and stable side-slope requirements · Characterize sediment dredgeability · Support sediment consolidation assessment for cap design · Support selection of dredge equipment · Support design of sediment handling, transport, dewatering, treatment systems, and disposal requirements	Area-specific geotechnical sampling and analysis of sediments, including: · Geologic characterization · Sediment index properties · Sediment strength and consolidation properties	Data must be obtained during design investigation/design engineering phases to support accurate design and ensure safe and reliable performance of completed remedy. Certain data may be collected by remedial construction contractor to support design of sediment and dewatering processing systems.			ü	ü	ü
Geophysical/Physical Information								
10	Perform detailed geophysical characterization to: · Support accurate dredge, cap, and debris quantity estimates · Support design of dredge and cap areas	Physical surveys: · Site-wide bathymetric and topographic surveys · Specialized surveys as appropriate for debris characterization (e.g., side-scan sonar, magnetometer, or sub-bottom profiling)	Data must be obtained during design investigation/design engineering to support accurate design.			ü	ü	
11	Obtain information regarding fixed structures to: · Assess constraints on future sampling activities, recovery categories, remedial technology assignments, and construction activities	Perform assessment and survey of in-water structures.	Perform early reconnaissance-level identification of all structures with the potential to influence recovery categories to inform future sampling and/or design analyses. Additional surveys/inspections of certain structures may also be performed during remedial design to support constructability and safety/stability analysis for dredging and capping activities. Remediation contractor will also perform pre-construction surveys to document structure conditions prior to construction.		ü	ü		ü
12	Physical/operational uses	Perform vessel/use survey.	Perform the vessel/use survey early to identify physical disturbances that may affect recovery categories, technology assignments, or design details. Review and update as needed during design investigation/design engineering.		ü	ü	ü	

No.	Data Need	Data Collection Activities	Timing Considerations	2015-2019 ENR/AC Pilot Study	2016-2019 Pre-Design Studies	TBD[b] Remedial Design Investigation[c]	TBD[b] Remedial Design Engineering[c,d]	TBD[b] Remedial Action[e]
13[h]	Evaluate sediment transport and erosion/scour/disturbance processes to support: · Delineation of MNR/ENR areas · Design of ENR/*in situ* treatment · Cap design · Outfall scour protection	Perform location-specific pilot testing and engineering analyses	The ENR/AC pilot study will provide information regarding the relative stability of AC with ENR The pre-design studies (waterway user survey and assessment of in-water structures) will provide information that can be used during design to inform development of parameters for evaluation of vessel-induced erosion/scour forces. During design, readily available hydrodynamic data[i] will be used to evaluate erosion/scour forces (due to river currents, vessels, outfall discharges, etc.) and associated stability of sediments, ENR/*in situ* treatment amendments, and cap materials.	ü	ü	ü	ü	
14[h]	Perform an assessment to evaluate effect of designed remedial elements (e.g., sediment cap, riverbank armor) on water surface elevations, velocities, shear stress, and sediment mobility.[g]	Cross section analysis or hydrodynamic modeling	Assessment to be performed as needed during design using the configuration of the remedy as designed.				ü	
Implementation Planning, and Other Information								
15[g]	Determine space requirements to establish construction support areas, including: · Transload facilities · Dredge material handling/stabilization areas · Construction water management/treatment · Laydown/material storage · Field office and support facilities	Identify space requirements and candidate sites.	Identify space and performance requirements to be performed in conjunction with remedial design to facilitate contractor bids. Identify specific properties and negotiation of access, lease, and/or purchase agreements to be performed by owners during engineering design or by the selected remedial contractor(s) during the remedial action.				ü	ü
16[g]	Haul routes	Identify transportation routes for truck/rail/barge transport of materials.	Identify minimum requirements in design with details developed in contractor's remedial action work plan.				ü	ü
17[g]	Determine current and reasonably anticipated future uses that may influence sampling design, recovery categories, technology assignments, delineation of remedial boundaries, and institutional controls.	Identify and document known or reasonably anticipated future waterway-dependent uses with potential to disturb sediment bed.	Determine uses early (i.e., pre-remedial design) to inform location-specific remedial design activities. Refine and verify information during design investigation/design engineering.		ü	ü	ü	

No.	Data Need	Data Collection Activities	Timing Considerations	2015-2019 ENR/AC Pilot Study	2016-2019 Pre-Design Studies	TBD[b] Remedial Design Investigation[c]	TBD[b] Remedial Design Engineering[c,d]	TBD[b] Remedial Action[e]
18[g]	Establish logistic or design details to accommodate waterway users that may be affected by remedial construction activities (e.g., Tribes, recreational users, facility operators, bridge operators, etc.).	Identify waterway users that may be affected by remedial construction activities. Collect information that may be used in coordinating access and/or temporary restrictions. Task includes development of vessel management plans and coordination with waterfront operators, recreational users, and tribal fishing representatives.	Pre-design investigation user survey (noted above) will be updated and refined throughout remedial design/remedial action phases to ensure the information is useful and current.		ü	ü	ü	ü
19[g]	Identify in-river and shoreline areas with cultural and archaeological resources and determine needed offsets for dredge/cap areas.	Establish area-specific delineation of archaeologically or culturally sensitive areas.	Identify areas during design, following establishment of dredge and capping limits, to facilitate coordination of any needed adjustments.			ü	ü	
20	Identify potential backfill and reactive amendment material sources.	Develop acceptance criteria; research and compile locally available sources and data.	Conduct preliminary identification of potential sources as part of remedial design, in conjunction with development of specifications. Remediation contractor will perform final identification/selection.				ü	ü
21	Perform bench-scale/treatability testing to support water treatment. [g]	Perform bench-scale tests, as-needed: · Column settling · Water treatability	Perform tests during remedial design, if needed based on dredging and water management requirements developed in design.				ü	

[a] The data needs and sequencing of data collection activities listed herein are expected to evolve as the remedial design progresses. The data needs have been identified in consideration of the technical elements and ARARs for the selected remedy. Data needs and objectives will be refined in response to new data/information that may become available, in coordination with EPA. In general, future remedial design investigations will include a summary and assessment of relevant existing data and data gaps, followed by focused, location-specific investigations and analyses. Other efforts, such those related to Institutional Controls, are also expected to continue in parallel with the remedial design processes.

[b] The timing of remedial design and remedial action will be evaluated as part of Task 10 of the pre-design studies.

[c] New remedial design field measurements (e.g., sampling, surveying) are primarily accomplished during “Remedial Design Investigation.”

[d] Remedial design engineering” includes agency, owner/operator, and stakeholder reviews and input on design packages (e.g., 30%, 60%, 90%, Final) with increasing development of details. Additional data needs are commonly identified during early design phases as design elements mature. Limited field studies may be needed during the design engineering phase to support final design details.

[e] Where noted, certain data needs are anticipated to be resolved in coordination with the selected remediation contractor; following remedial design but prior to implementation. Remedial action includes development of remedial action work plan with specific means and methods proposed by the contractor. Remedial action work plan includes agency, owner/operator, and stakeholder reviews/input.

[f] Preliminary ENR and MNR areas were established in Figure 18 of the ROD (EPA 2014) based on RI/FS data. The boundaries of these areas are likely to change based on design-level sampling and evaluations. This work plan refers to these areas simply as ENR and MNR areas, but it is acknowledged that these areas are preliminary and likely to change.

[g] The need for these data will be confirmed during remedial design engineering based on design approaches and evaluation of existing data.

[h] Data collection and/or input parameterization will consider potential influence of regional climate change and associated long-term resiliency of the remedy.

AC – activated carbon
ARAR – applicable or relevant and appropriate requirement
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
ENR – enhanced natural recovery
EPA – US Environmental Protection Agency
LDW – Lower Duwamish Waterway
MIT – Massachusetts Institute of Technology
MNR – monitored natural recovery
PCB – polychlorinated biphenyl
RAL – remedial action level
RARE – Regional Applied Research Effort
RI/FS – remedial investigation/feasibility study
ROD – Record of Decision
SCO – sediment cleanup objective
95UCL – 95% upper confidence limit for the mean

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APPENDIX E. PRE-DESIGN STUDIES WORK PLAN – POREWATER ADDENDUM

Lower Duwamish Waterway Group

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

PRE-DESIGN STUDIES WORK PLAN –POREWATER ADDENDUM

FINAL

Prepared for

Lower Duwamish Waterway Group

For submittal to

US Environmental Protection Agency

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Table of Contents

Tables

Figures

Maps

Acronyms

AC	activated carbon
AOC	Administrative Order on Consent
BSAF	biota-sediment accumulation factor
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
DEQ	Department of Environmental Quality
DGT	diffuse gradient in thin-film
DL	detection limit
DQO	data quality objective
dw	dry weight
EFDC	Environmental Fluid Dynamics Code
ENR	enhanced natural recovery
EPA	US Environmental Protection Agency
HHRA	human health risk assessment
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
MIT	Massachusetts Institute of Technology
MNR	monitored natural recovery
OC	organic carbon
ORD	Office of Research and Development
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PDMS	polydimetyhylsiloxane
PE	polyethylene
POM	polyoxymethylene
PRC	performance reference compound
QAPP	quality assurance project plan
RAL	remedial action level

RARE	regional applied research effort
RBTC	risk-based threshold concentration
RI/FS	remedial investigation / feasibility study
RM	river mile
ROD	Record of Decision
SERDP	Strategic Environmental Research and Development Program
SETAC	Society of Environmental Toxicology and Chemistry
SMS	Washington State Sediment Management Standards
SPME	solid-phase microextraction
SWAC	spatially weighted average concentration
TEQ	toxic equivalent
TOC	total organic carbon
TTL	target tissue level
USACE	US Army Corps of Engineers
ww	wet weight

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1 Introduction

This addendum to the Lower Duwamish Waterway (LDW) Pre-Design Studies Work Plan (Windward and Integral 2017) presents the approach for porewater. It identifies porewater data quality objectives (DQOs), discusses the porewater data that are available within the LDW, and describes how the DQOs will be met to address porewater pre-design study elements in the third amendment to the Agreed Order on Consent (AOC) (EPA 2016).

The DQOs for the collection and analysis of LDW porewater are:

- **DQO 1** –Assess the relationship between concentrations of arsenic and carcinogenic polycyclic aromatic hydrocarbons (cPAHs) in clam tissue, porewater, and sediment to help evaluate whether achieving sediment cleanup levels for these contaminants of concern (COCs) will reduce concentrations in clam tissue to target tissue levels (TTLs) (Section 2).
- **DQO 2** – Estimate baseline porewater concentrations in monitored natural recovery (MNR) and enhanced natural recovery (ENR) areas[1] for polychlorinated biphenyls (PCBs) and dioxins/furans. This DQO is primarily intended to help assess the effect of reduced sediment concentrations on biota exposure and tissue concentrations (Section 3).

DQO 2 has been narrowed to focus on porewater baseline for PCBs and dioxins/furans and does not include arsenic and cPAHs. Arsenic and cPAHs are COCs for human health due to their concentrations in clams. DQO 1 addresses the relationships among clam tissue, porewater, and sediment as described in Section 2. Existing arsenic data, along with cPAH data to be collected to achieve DQO 1, are expected to address data needs related to clams and their ingestion by humans. For this reason, additional sampling to establish porewater baseline for DQO 2 is not required at this time. The data evaluation report will consider the results of sediment sampling for baseline arsenic and cPAHs and assess whether other data gaps remain.

This addendum evaluates existing data related to these DQOs, and where data gaps are identified, a conceptual sampling plan is proposed. In addition to the proposed collection and evaluations of porewater discussed in this addendum, porewater data collection or equilibrium partitioning modeling may be conducted as part of remedy design, or as part of assessing remedy effectiveness in cap areas, depending on site-specific questions and data needs.

[1] Preliminary ENR and MNR areas have been established in Figure 18 of the Record of Decision (ROD) (EPA 2014) based on remedial investigation/feasibility (RI/FS) data. The boundaries of these areas may change based on design-level sampling and evaluations. This memorandum refers to these areas simply as ENR and MNR areas, but it is acknowledged that these areas are preliminary.

2 Clam Tissue-Sediment Relationship for Arsenic and cPAHs

As discussed in the LDW human health risk assessment (HHRA) and RI (Windward 2007, 2010), 95% or more of the arsenic and cPAH risk to human health associated with seafood consumption is from the consumption of clams. In the LDW, *Mya arenaria*, commonly referred to as eastern softshell clam, is the clam species of harvestable size upon which human health seafood consumption risks were based. This is because *M. arenaria* is the most abundant edible-size clam species in the LDW. Their relative abundance may be related to their ability to tolerate low salinities and rapid salinity changes common in estuarine environments. *M. arenaria*, a filter-feeding clam,[2] feeds from the water column.

As part of the LDW RI, efforts were made to determine a relationship between sediment and clam tissue so that a sediment risk-based threshold concentration (RBTC) could be developed. However, the resulting relationships for both arsenic and cPAHs were found to be too uncertain for use in RBTC development. Thus, the US Environmental Protection Agency's (EPA's) LDW ROD (EPA 2014) stated that additional research would be conducted during the remedial design phase to further study the relationships between arsenic and cPAHs concentrations in clam tissue and sediment. This section addresses pre-design study porewater DQO 1, which is to assess the relationship between concentrations of arsenic and cPAHs in clam tissue, porewater, and sediment to help evaluate whether achieving sediment cleanup levels for these COCs will reduce concentrations in clam tissue to target tissue levels.

2.1 ARSENIC

This section presents a summary of existing LDW-specific data for arsenic, and provides a data gap evaluation of whether existing arsenic data are sufficient to address DQO 1.

2.1.1 Summary of available data

The relationship between arsenic concentrations in clam tissue and sediment was evaluated in detail in the LDW RI (Windward 2010). In addition, since issuance of the ROD (EPA 2014), additional work to better understand this relationship has been conducted as part of a Regional Applied Research Effort (RARE) study undertaken by EPA (Office of Research and Development [ORD] and Region 10) and the US Army Corps of Engineers (USACE) (Kerns et al. 2017). In both the RI and the RARE studies, the relationship between inorganic arsenic[3] concentrations in clam tissue and total arsenic concentrations in sediment was found to be significant, although there was considerable uncertainty in the regression. The RARE study also found that there was a

[2] Filter-feeding clams are a sub-group of suspension feeders that feed by straining suspended matter and food particles from water. *M. arenaria* bring in water through an intake siphon, which extends from its shell to the surface of the mud, where it filters water to obtain food and oxygen.

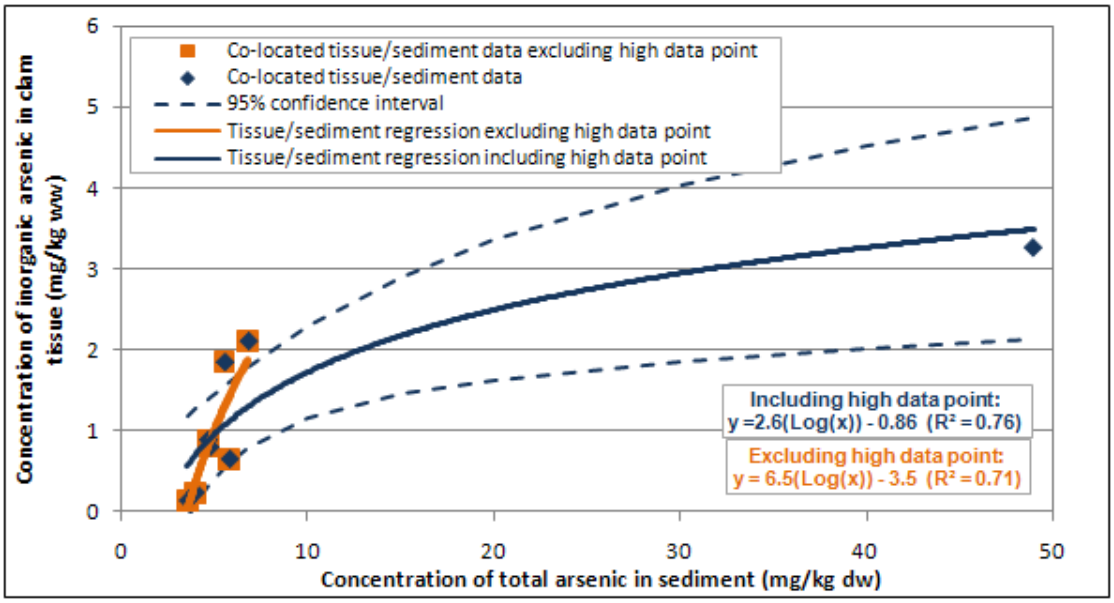
significant relationship between concentrations of inorganic arsenic in clam tissue and concentrations of total arsenic in porewater, as well as between total arsenic in porewater and sediment.

2.1.1.1 LDW RI

In the LDW RI, the relationship between inorganic arsenic concentrations in *M. arenaria* and total arsenic concentrations in sediments was studied extensively (Windward 2010). Among the variables investigated were differences in inorganic arsenic analytical results in splits from several laboratories, relationships using data from clams (both *M. arenaria* and other clam species) collected in other locations in Puget Sound, spatial assumptions in the sediment area used in the regression, and possible relationships between arsenic in clams and surface water (although co-located surface water data were not available). Ultimately, none of these efforts resulted in an improved regression of inorganic arsenic concentrations in *M. arenaria* tissue with total arsenic in LDW sediment.

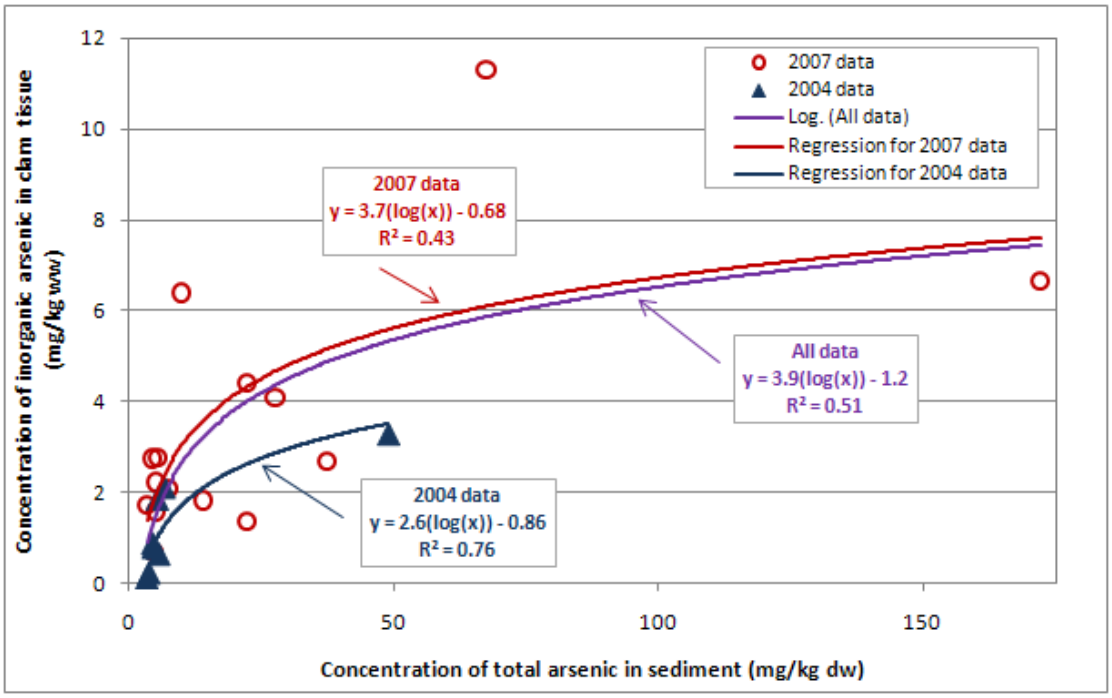
Regression equations developed using co-located clam tissue and sediment data collected in 2004 (n = 8, with total arsenic concentrations in sediment ranging from 3.53 to 49 mg/kg dry weight [dw]) had wide confidence intervals, and the regressions were highly influenced by a single high data point (Figure 2-1). Additional data collected in 2007 increased the range of concentrations in the dataset (n = 23, with total arsenic concentrations in sediment ranging from 3.53 to 172 mg/kg dw), making the evaluation more widely applicable but confirming the variability in this relationship. The additional data collected in 2007 did not improve the fit of the relationship, as evidenced by the lower R^2 values (Figure 2-2).

[3] Inorganic arsenic was the COC evaluated in the HHRA, because inorganic arsenic is more toxic to humans and is the basis for the toxicity values. Thus, EPA guidance recommends the use of inorganic arsenic tissue concentration data for the purposes of evaluating human health risks based on seafood consumption (EPA 2000). The cleanup levels and remedial action levels (RALs) for arsenic in sediment are based on total arsenic (inorganic plus organic species), so total arsenic is analyzed in sediment.



Source: Windward (2010)

Figure 2-1. Logarithmic regression of inorganic arsenic concentrations in LDW clam tissue relative to total arsenic concentrations in co-located sediment samples collected in 2004



Source: Windward (2010)

Figure 2-2. Logarithmic regression of inorganic arsenic concentrations in LDW clam tissue relative to total arsenic concentrations in co-located sediment using 2004 and 2007 data

As part of the LDW RI (Windward 2010), additional models were evaluated in an attempt to find one that better fit the arsenic clam and co-located sediment dataset. This evaluation found that, like the regressions presented in Figures 2-1 and 2-2, other model types that could have been applied to the data (e.g., hockey stick regression) would also have been driven by the high data point. Thus, although the linear model with log-transformed sediment data was able to explain only 51% of the variance in tissue concentrations, it was the model that was best able to describe the data.

The high level of variability in clam tissue concentrations that was not explained by the sediment concentrations resulted in wide confidence intervals around the regression. Therefore, it was concluded in the RI that the relationship between total arsenic in sediment and inorganic arsenic in clam tissue should not be relied upon for sediment RBTC development (Windward 2010). The ROD suggested that additional research be done, resulting in the RARE study, which is described in Section 2.1.1.2.

2.1.1.2 RARE study

The uncertainty in the arsenic relationships reported in the RI (Windward 2010) was further investigated in the two-phase RARE study. The first phase was a laboratory mesocosm study conducted using LDW sediments (Lotufo et al. 2014), and the second phase was an *in situ* field study conducted in two plots within the LDW (USACE 2015; Kerns et al. 2017).

Phase 1: Initial Laboratory Study

The initial laboratory mesocosm study assessed arsenic bioaccumulation in *M. arenaria* from two potential exposure pathways: 1) uptake from bedded sediments, and 2) uptake from suspended solids (Lotufo et al. 2014). The bedded sediment exposures were conducted by placing adult clams[4] in LDW sediments for 60 days. Sediment was collected from intertidal areas north of Kellogg Island and Slip 1, combined, and homogenized. This sediment was used to conduct the two treatments:

- **Bedded sediment exposure** – These clams were exposed to homogenized sediment, which had an average total arsenic concentration of 191 mg/kg.

[4] Clams were field collected from a site in Maine considered to be pristine. However, in consideration of some variability in initial tissue concentrations, the clams were held in clean water for 30 days to lower the arsenic concentrations in their tissues prior to study exposure.

- **Suspended sediment exposure** – These clams were exposed to suspended sediment by first wet sieving the homogenized LDW sediment through a 250-µm sieve (resulting in a total arsenic concentration of 59 mg/kg).[5] The fine sediments (total suspended solids concentration of approximately 24 mg/L) were then circulated in a flow-through exposure system containing the clams for 60 days. Clams in this treatment were not embedded in sediment, and sediment that collected at the bottom of the tank was removed weekly.

This initial phase of the RARE study concluded that, for *M. arenaria*, the bedded sediment exposure pathway was more influential than the suspended sediment pathway for both total arsenic and the sum of inorganic arsenic species (Lotufo et al. 2014), although the relative magnitudes of these exposures were not specified.

Phase 2: ***In Situ*** **Field Study**

The second part of the RARE study (USACE 2015; Kerns et al. 2017) was conducted by exposing *M. arenaria* in the LDW *in situ*, whereby clams were exposed to arsenic through all LDW pathways. In addition to evaluating the relationship between inorganic arsenic in clam tissue and total arsenic in sediment, study objectives included assessing the potential relationship between arsenic concentrations in porewater and clam tissue. USACE and EPA are finalizing the data report for Phase 2 of the RARE study as of the date of this addendum.

In the *in situ* study, a total of five treatments were conducted in two test plots (Map 1). For each treatment, adult clams were deployed in six bottomless buckets (i.e., six replicates were analyzed per treatment area).

- **High sediment concentration plot** – This plot was located at river mile (RM) 3.75, where total arsenic concentrations in sediment were anticipated to be high (generally > 93 mg/kg dw based on the LDW RI dataset), which was considered relevant to pre-remediation concentrations of total arsenic in sediment (Kerns et al. 2017). Treatments in this plot included homogenized sediment, a sand treatment plot, and an iron-amended plot. The actual mean concentration of total arsenic was 26 mg/kg dw in the homogenized sediment treatment, and was 6.0 mg/kg in the iron-amended treatment. The sand used for the sand treatment plot was not analyzed; the arsenic concertation was assumed to be low.
- **Low sediment concentration plot** – This plot was located at RM 3.9, where total arsenic concentrations in sediment were anticipated to be low (generally

[5] The total arsenic concentration in the sieved sediment fraction (59 mg/kg) was lower than that in the un-sieved sediment (191 mg/kg). As reported by Lotufo et al. (2014), the material remaining in the sieve was primarily composed of shell fragments. After the experiment was complete, a portion of sediment used in the study was sieved, and total arsenic concentrations were 309 mg/kg for material > 2 mm in diameter, 999 mg/kg for material between 250 µm and 2 mm in diameter, and 66 mg/kg for material that passed through the 250-µm sieve.

< 12 mg/kg dw based on the LDW RI dataset), which was considered relevant to post-remediation concentrations of total arsenic in sediment (Kerns et al. 2017). Treatments in this plot included undisturbed sediment and homogenized sediment. The actual mean concentrations of total arsenic were 6.3 and 7.5 mg/kg dw in the undisturbed and homogenized treatments, respectively.

The mean concentrations of total arsenic detected in the high and low concentration plots for all treatments were less than both the LDW-wide RAL (57 mg/kg) and the RAL for intertidal areas (28 mg/kg).

Total and inorganic arsenic concentrations in clam tissue were analyzed following 180 days of *in situ* exposure for each treatment. The main-body tissues (whole body minus siphon skin) were analyzed for total and inorganic arsenic in each replicate (n = 30), and the siphon skin tissues were analyzed separately for a subset of the replicates in two of the treatments (n = 6). Total arsenic concentrations in sediment were analyzed in all replicates (n = 24), except for the sand treatment. Total arsenic concentrations in porewater for these same 24 replicates were analyzed by centrifuging the sediment and then filtering (< 45 µm) the supernatant (n = 24).[6] In addition, for a subset of treatments (all but the sand and iron-amended treatments), total arsenic concentrations in porewater were measured using diffusive gradient in thin-film (DGT) samplers (n = 15). Total arsenic concentrations were analyzed in whole-water samples once during the study (toward the end of the 190-day exposure period).

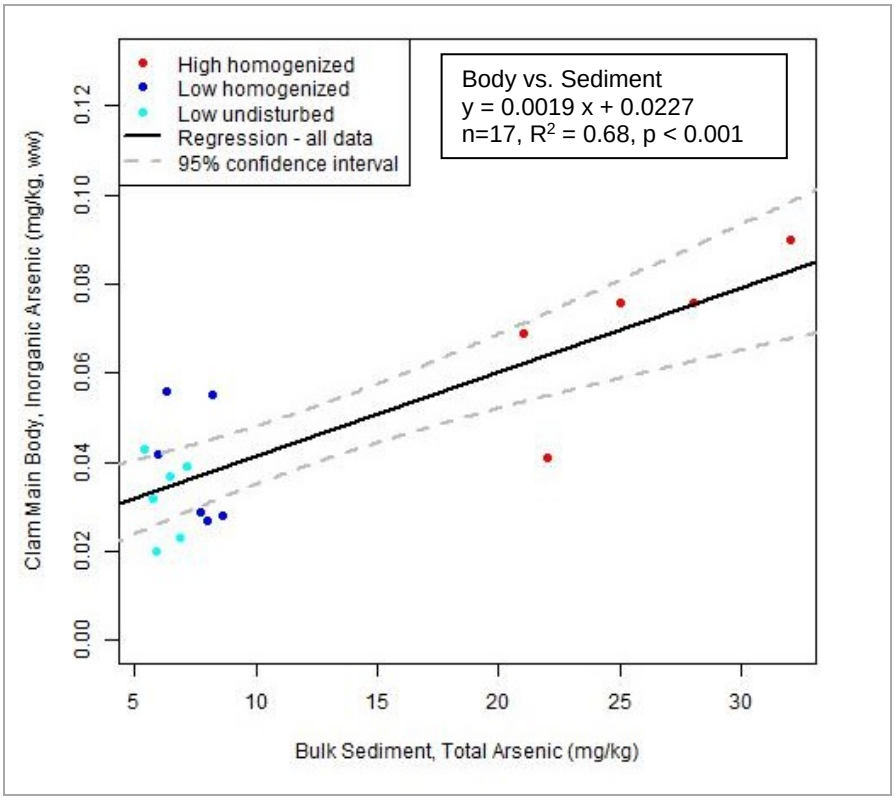
Evaluation of Tissue-sediment Relationship

Data collected as part of the RARE study (Kerns et al. 2017) indicated that the relationship between sediment and clam tissue for arsenic was best described using total arsenic concentrations in bulk sediment and inorganic arsenic concentrations in main-body clam tissues (Figure 2-3).[7] This relationship was found to be significant ($p < 0.001$), but the R^2 was modest (0.68),[8] indicating that nearly one-third of the variability in the dataset was not explained by the regression (Figure 2-3). Data from the iron-amended plot were excluded from the regression because the iron amendment likely altered the bioavailability of arsenic in sediment, possibly resulting in a different tissue-sediment relationship.

[6] These data were discounted as unreliable in the study Kerns et al. (2017).

[7] Kerns et al. (2017) also reported a positive relationship between total arsenic in bulk sediment and inorganic arsenic in siphon skin, although this relationship was based on a small sample size ($R^2 = 0.93$, $p = 0.02$, $n = 5$).

[8] The R^2 of 0.68 presented herein is based on LDWG's evaluation conducted as part of this document. This value is different than the R^2 of 0.59 reported in the RARE study (Kerns et al. 2017), because of differences in rounding during the regression evaluation process, and because data from the iron-amended plot were not included in LDWG's evaluation presented herein.



Note: The gray dashed lines indicate the 95% confidence limits.

Figure 2-3. Regression of inorganic arsenic concentrations in main-body clam tissue relative to total arsenic concentrations in co-located sediment samples from the *in situ* portion of the RARE study

When evaluating these regression relationships, it is important to recognize that the distribution of the bulk sediment concentrations was skewed towards the low end of the concentration range, with most of the samples having concentrations < 9 mg/kg dw. The overall range of sediment concentrations was between 4.4 and 32 mg/kg dw.[9]

The variability around the regression relationship was between 31 and 42% of the total variability (i.e., 1 minus the R^2 values of 0.59 and 0.68[10]), suggesting that although sediment is one factor that contributes to inorganic arsenic concentrations in clam

[9] For comparison, the RAL for total arsenic is 57 mg/kg for surface sediments applied site-wide and 28 mg/kg for the top 45 cm of sediment in intertidal areas; the site-wide arsenic cleanup goal as specified in the ROD is 7 mg/kg (EPA 2014). Following remediation, the LDW-wide spatially weighted average concentration (SWAC) is predicted to decrease from 16 to 9 mg/kg, and the SWAC for the clamming areas is predicted to decrease from 13 to 9 mg/kg.

[10] The R^2 values presented herein (0.59 and 0.68) are for the regression of inorganic arsenic in main-body clam tissue versus total arsenic in bulk sediment, both with the iron-amended treatment (0.59 in Figure 3 of Kerns et al. (2017)) and without (0.68 in Figure 2-3).

tissue, other factors (e.g., surface water and suspended particles) are likely also important.

Another source of potential uncertainty when considering tissue-sediment regressions for clams is that whole-body clam tissue concentrations were not directly measured, but rather were mathematically estimated based on concentrations in siphon skin and main-body tissue. However, although this source of uncertainty may increase the variability in estimated whole-body clam tissue concentrations, the measurement error is anticipated to be unbiased (i.e., random), meaning that the overall conclusions from a regression using the estimated whole-body concentrations should not be affected.

Siphon Skin Data and Implications for Target Tissue Level

Another important conclusion from the RARE study was related to siphon skin tissue samples. Consistent with the findings of an Oregon Department of Environmental Quality (DEQ) study (Oregon DEQ 2015), the RARE study found that concentrations of inorganic arsenic detected in siphon skin (19.0 to 65.0 mg/kg wet weight [ww]) were significantly higher than those detected in main-body tissue (0.02 to 0.09 mg/kg ww) (Kerns et al. 2017). The clam TTL for inorganic arsenic is 0.09 mg/kg ww (EPA 2014).

Porewater Role

As part of the RARE study, concentrations of arsenic in porewater were analyzed to evaluate whether porewater data improved understanding of the clam tissue-sediment relationship. The results indicated that the limited porewater data (n = 15) did not improve the ability to predict inorganic arsenic concentrations in clam tissue, because 1) the clam tissue-sediment relationship was stronger than the clam tissue-porewater relationship,[11] and 2) a strong positive correlation existed between total arsenic concentrations in 63–250-µm-fraction sediment and in porewater (R^2 = 0.92, p-value < 0.001[12]), meaning that changes in sediment concentrations resulted in similar changes in porewater concentrations in this range.

2.1.2 Data gap evaluation

The data summarized above were used to assess DQO 1, and it was determined that:

- **The available porewater data did not help to explain the bioaccumulation of inorganic arsenic by** *M. arenaria*. The RARE study demonstrated that concentrations of total arsenic in porewater were closely related to those in

[11] LDWG's evaluation of the RARE study data showed that although the R^2 values were relatively similar (0.68 and 0.62 for the clam tissue-sediment and porewater regressions, respectively), the confidence intervals were larger for the clam tissue-porewater regression. Thus, as measured by goodness of fit (R^2) and confidence interval width, the porewater regression had a worse fit with more uncertainty than the sediment regression.

[12] These results were reported in Figure 3 of Kerns et al. (2017). LDWG's evaluation of the RARE study data also found a strong relationship between total arsenic in bulk sediment and in porewater, excluding the bulk sediment outlier (R^2 = 0.90; p-value < 0.001).

sediment, and that the relationship between clam tissue and sediment was stronger than that between clam tissue and porewater (Kerns et al. 2017). Thus, the available porewater data did not help to explain the variance around the clam tissue-sediment relationship.

- **Both the RI and the RARE studies found a moderate clam tissue-sediment relationship**. Moderate-strength clam tissue-sediment relationships were developed using data from the LDW RI (Windward 2010), as presented in Figure 2-2, and from the RARE study (Kerns et al. 2017), as presented in Figure 2-3. The considerable uncertainty around the regressions suggests that additional non-sediment factors are important.
- **The TTL for whole clams can be achieved in main-body clam tissue (excluding siphon skin) with the current remedy**. As discussed in the RARE study (Kerns et al. 2017), inorganic arsenic concentrations in main-body tissue are predicted to reach the TTL of 0.09 mg/kg at a sediment concentration of 36 mg/kg total arsenic, which is greater than the intertidal RAL for total arsenic of 28 mg/kg dw and the site-wide sediment cleanup goal of 7 mg/kg dw.

Based on these determinations, no additional porewater data are proposed for arsenic, because 1) it is not expected that this information would better explain the clam tissue-sediment relationship, and 2) it would not better predict how clam tissue concentrations would be expected to decrease following remediation.

Based on the regression analysis presented in the RARE study, (Kerns et al. 2017) concluded that LDW Superfund site remediation and associated reductions in total arsenic sediment concentrations will result in reductions in inorganic arsenic concentrations in clam tissue. As described in the RARE study, the sediment RAL for arsenic appears to be sufficiently low that inorganic arsenic concentrations in main-body clams are predicted to meet 0.09 mg/kg ww, the TTL for whole clams. Concentrations of inorganic arsenic in the siphon skin may not be reduced sufficiently to allow the combined main-body and siphon skin tissue (i.e., the whole clam) to achieve the TTL. Consumption of whole clams is a potential exposure route for tribal and subsistence harvesters. The RARE study further notes that sediment is not the only exposure pathway for clams. In addition to porewater, arsenic in surface water and solids (including suspended materials and phytoplankton) at the sediment-water interface may affect clam tissue concentrations. However, given the strength of the correlation between arsenic concentrations in sediment and clam tissue, additional porewater data collection is not required at this time.

2.2 cPAHs

The ROD stated that additional research would be conducted for cPAHs to better understand the relationship between concentrations in clam tissue and sediment. This section discusses the available information for the LDW and relevant studies from the

literature, and ultimately outlines an investigation to be conducted based on a data gaps evaluation.

2.2.1 Summary of available data

As part of the LDW RI (Windward 2010), the relationship between cPAH toxic equivalents (TEQs) in clam tissue and those in sediment was investigated. As for arsenic, various attempts to develop a regression relationship between co-located clam tissue and sediment suitable for the development of a sediment RBTC were not successful. The high level of uncertainty in the regression relationship indicates that variables other than sediment concentrations are important.

2.2.1.1 LDW RI

Co-located clam tissue and sediment data from 14 beaches in the LDW were used to develop a cPAH regression model in the RI (Windward 2010). cPAH TEQs in sediment ranged from 23 to 7,100 µg/kg dw, or from 23 to 520 µg/kg dw when the high value was excluded. The data, regression model, and 95% confidence intervals for the regression are presented in Figures 2-4 (logarithmic scale) and 2-5 (arithmetic scale). Additional details regarding the development of these regressions are presented in Appendix E of the LDW RI.

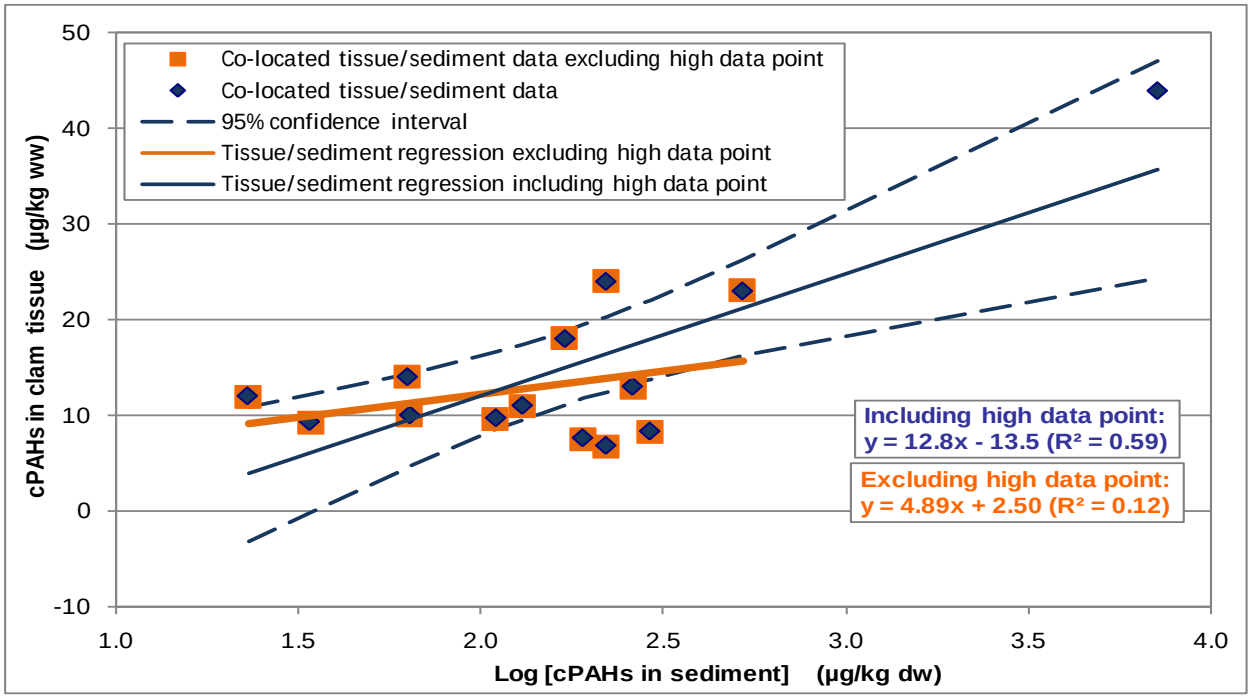


Figure 2-4. Logarithmic regression of cPAH TEQs in LDW clam tissue relative to concentrations in co-located sediment using arithmetic tissue data and log[sediment] data

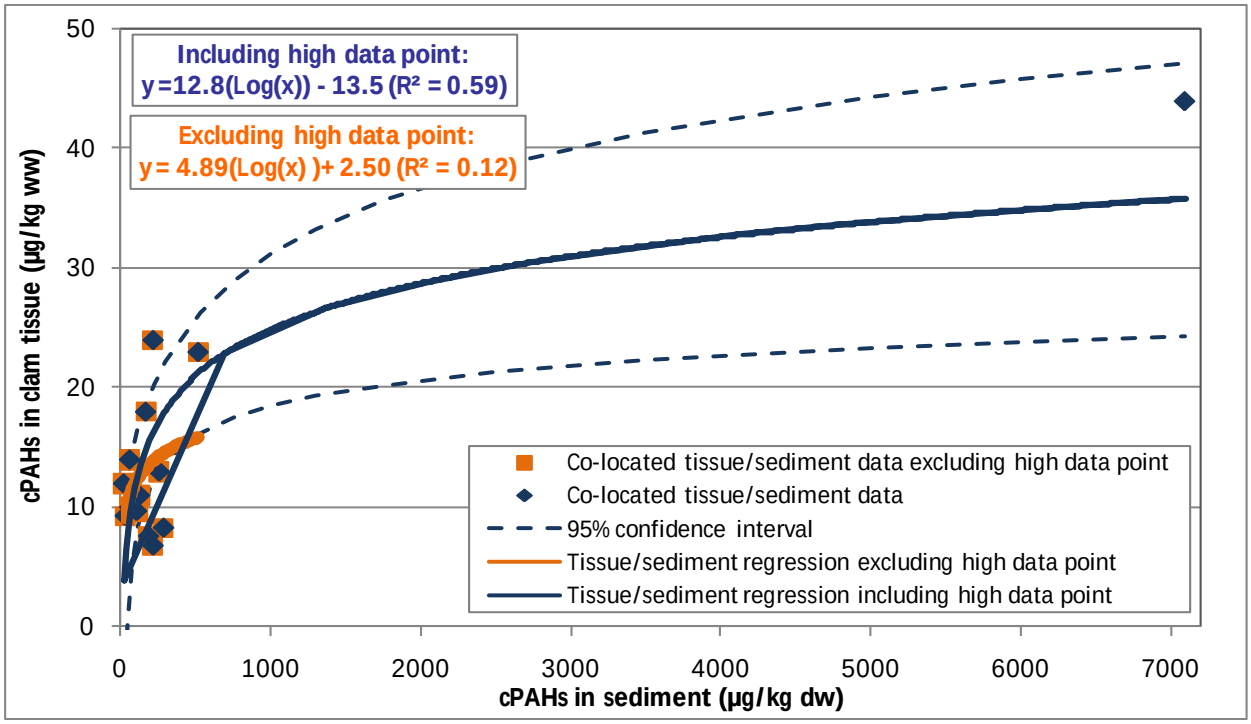


Figure 2-5. Logarithmic regression of cPAH TEQs in LDW clam tissue relative to concentrations in co-located sediment presented on arithmetic scale

The LDW RI (Windward 2010) identified a number of uncertainties associated with the cPAH TEQ regression that made the regression model unsuitable for the purpose of sediment RBTC development. These uncertainties include the following:

- **Impact of the highest data point** – This data point had a large impact on the shape and significance of the regression curve. Furthermore, without this data point, the regression was no longer significant.
- **Low R^2 values** – Without the highest data point, only a small percentage of the variance was explained by the regression ($R^2 = 0.12$), suggesting that other variables are likely more important.
- **Confidence intervals** – As shown in Figures 2-4 and 2-5, the broad width of the confidence intervals indicates considerable uncertainty in this relationship.

Each of these uncertainties is described in more detail in the RI (Windward 2010). As with arsenic, efforts as part of the LDW RI to evaluate whether a more complicated statistical model could better describe the relationship between tissue and sediment concentrations were also unsuccessful.

Based on the uncertainties identified, the tissue-sediment relationship developed as part of the LDW RI (Figures 2-4 and 2-5) (Windward 2010) could not be used to reliably understand whether the selected remedy would achieve the clam cPAH TTL of 0.24 µg/kg ww (EPA 2014), which is based on the species-specific RBTC for the 1×10^{-6} risk level, as presented in the LDW FS (AECOM 2012). Because of the wide confidence

intervals, a single sediment concentration could correspond to predicted tissue concentrations that varied by an order of magnitude.

2.2.1.2 Literature review

Because the RARE study (USACE 2015) did not investigate cPAHs, the literature was reviewed to determine if cPAH studies had been conducted with *M. arenaria*, porewater, and sediment at other locations. The following information was found.

- Two studies (Foster et al. (1987) and Rust et al. (2004)) reported low accumulation of polycyclic aromatic hydrocarbons (PAHs) by *M. arenaria* from sediment[13] (although higher accumulation than that of other filter feeders). These studies supported the conclusion that non-sediment factors are also important in understanding bioaccumulation in *M. arenaria.*
- Other studies investigated whether freely dissolved PAH concentrations determined using polyethylene (PE) passive sampling approaches could serve as better predictors of PAH bioaccumulation in *M. arenaria* than sediment concentrations using equilibrium partitioning approaches. Lohmann et al. (2004) concluded that PAH bioaccumulation in clams was a function of freely dissolved concentrations in both surface water / suspended particles (determined using passive samplers) and bedded sediment. Fernandez and Gschwend (2015) concluded that porewater concentrations (determined using passive samplers) were better predictors of concentrations in *M. arenaria* tissue than the traditional sediment-tissue biota-sediment accumulation factor (BSAF) approach.
- Another important factor that has been shown to influence bioaccumulation is the amount and quality of carbon in sediment. The presence of black carbon (e.g., soot) has been shown to reduce freely dissolved cPAH concentrations in sediment porewater (Cornelissen et al. 2005; Ghosh et al. 2003), which can translate into reduced cPAH exposure for sediment-dwelling organisms (Hawthorne et al. 2007; EPA 2012). Both Rust et al. (2004) and Thorsen et al. (2004) found that the presence of soot reduced cPAH bioaccumulation in *M. arenaria*, although the magnitude of this effect was relatively small for this species when compared with the magnitude for other organisms. Rust et al. (2004) reported that filter-feeding *Mulinia lateralis* and *M. arenaria* accumulated approximately 1.5 times more PAHs in laboratory treatments without soot than in those with soot, while the deposit-feeding *Macoma balthica* and polychaete *Nereis virens* accumulated 4.8 and 22 times, respectively, more cPAHs in non-soot treatments than in soot treatments. These studies further support the conclusion that factors other than bulk sediment concentration are also important in understanding bioaccumulation for *M. arenaria.*

[13] The strength of the relationship between tissue and co-located sediment concentrations was not evaluated in these studies.

Overall, the reviewed studies indicated that understanding freely dissolved PAH concentrations in porewater may improve the ability to relate cPAH concentrations in sediment and clam tissue (Hawthorne et al. 2007; Fernandez and Gschwend 2015; EPA 2012). Although it is unknown how well cPAH concentrations in porewater and sediment are correlated in the LDW, the available information suggests that porewater concentrations are controlled by various factors, including 1) the concentration of the contaminant in bulk sediment, and 2) the sorptive properties of the sediment (i.e., the amount and type of carbon in the sediment).

2.2.2 Data gap evaluation

The data summarized in Section 2.2.1 and its subsections were used to assess DQO 1. In summary, it was determined that:

- **The clam tissue-sediment relationship is weak or non-existent for cPAHs in the LDW**. Evaluations conducted as part of the LDW RI (Windward 2010) indicated that the relationship between cPAHs in clam tissue and sediment is weak or non-existent (with R^2s varying from 0.12 to 0.59, depending on the inclusion of a high data point), and that other factors are likely important in determining cPAH bioaccumulation in *M. arenaria* tissue.
- **The weak clam tissue-sediment relationship is supported by the available literature**. The literature indicates that bioaccumulation by *M. arenaria* is likely influenced by factors such as concentrations of contaminants in surface water and suspended particulates, and the partitioning of contaminants between sediment and porewater.
- **No RARE-type study is available for cPAHs**. Unlike arsenic, no LDW-specific RARE study has been conducted for cPAHs to evaluate the influence of porewater on the clam tissue-sediment relationship.

Because the available information is inconclusive regarding the utility of cPAH porewater data, an investigation to evaluate co-located clam tissue, sediment, and porewater data is proposed to provide site-specific information to determine if porewater data are helpful in better understanding uptake of cPAHs by *M. arenaria* in the LDW.

2.2.3 cPAH investigation

As part of the pre-design studies in the LDW, a cPAH porewater investigation will be conducted to address DQO 1. In the cPAH investigation, cPAH concentrations in co-located intertidal sediment, clam tissue, and porewater will be analyzed to assess the utility of porewater data in better understanding the clam tissue-sediment relationship. An overview of the proposed study design is provided in Figure 2-6, and discussed in the subsections that follow. In brief, co-located *M. arenaria* and sediment composite

samples will be collected from 20 candidate intertidal locations throughout the LDW. These samples will be analyzed for cPAHs,[14] and a minimum of 10 locations will be selected for further evaluation based on the range of cPAHs in both sediment and tissue samples. The selected sediment samples will then be used in an *ex situ* investigation of porewater using passive samplers. The final data analysis will involve developing a correlation between porewater and tissue concentrations for individual PAHs (i.e., not for cPAH TEQ).

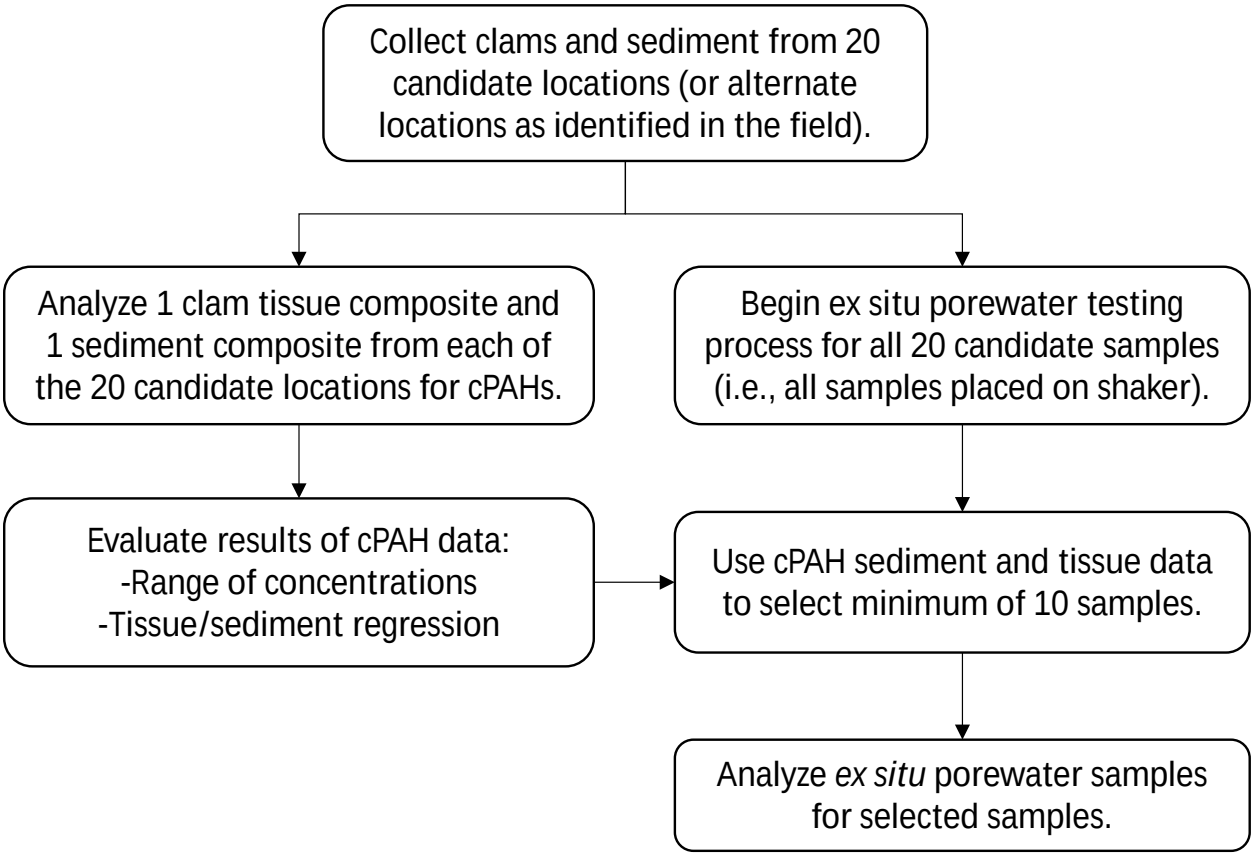


Figure 2-6. Conceptual cPAH porewater sampling design

Although porewater concentrations could also be measured as part of an *in situ* study, an *ex situ* method will be used for two reasons. First, an *ex situ* investigation reduces the risk of sampler loss, maximizing the available data. Second, uncertainty regarding measured porewater concentrations is lower when using *ex situ* methods, because equilibration can be accelerated in the laboratory by agitating the sample (Jalalizadeh and Ghosh 2016), resulting in smaller equilibrium corrections using performance reference compound (PRC) data. When larger corrections are needed, additional

[14] Clam tissue will also be analyzed for lipids, and bulk sediment will also be analyzed for total organic carbon (TOC) and black carbon.

uncertainty in the estimates of porewater concentrations is introduced (Ghosh et al. 2014).

2.2.3.1 Selection of candidate sampling locations

Twenty preliminary sampling locations have been identified[15] within the clamming areas in the LDW (Table 2-1, Maps 2 and 3) based on the following criteria:

- Representative locations within clam tissue collection areas identified as part of the baseline sampling program (particularly those locations with higher clam densities)
- Representative of the relevant range[16] of cPAH TEQs in ENR/MNR areas

These locations were selected to represent a range of cPAH TEQs in sediment where clams may be present in reasonably high densities. As needed, the locations may be modified in the field to utilize locations where clams can be collected in close proximity. More details, including the identification of sample locations, will be provided in the clam tissue QAPP.

[15] Preliminary locations may be modified and will be specified in the clam tissue quality assurance project plan (QAPP), wherein the details for this investigation will be documented.

[16] The range of concentrations in ENR/MNR areas is approximately 4.3 to 1,900 µg/kg, based on the LDW RI surface sediment dataset.

Table 2-1. Preliminary cPAH porewater sampling areas in order of increasing cPAH TEQ

Candidate cPAH Sampling Area[a]	RM	Clam Tissue Collection Area	Estimated cPAH TEQ based on RI/FS IDW Interpolation (µg/kg dw)		Remedy Type
			Estimated Concentration Category	Estimated Average Concentration	
2	0.2	1	very low (< 60)	13	MNR
14	3.0	9	very low (< 60)	32	MNR
6	0.85	2	very low (< 60)	34	MNR
12	2.8	8	low (60–90)	72	ENR
19	3.8	10	low (60–90)	85	MNR
11	2.1	6	low to medium-low (60–150)	108	MNR
13	2.9	9	medium-low (90–150)	110	MNR
20	3.95	10	medium-low (90–150)	110	MNR
16	3.35	9	medium-low (90–150)	118	MNR
15	3.1	9	medium-low (90–150)	140	MNR
5	0.7	3	medium-low to medium (90–380)	200	MNR
4	0.7	2	medium (150–380)	220	MNR
9	1.8	5	medium (150–380)	260	MNR
10	1.8	5	medium-high (380–900)	520	MNR
8	1.5	4	medium-high to high (380–1,500)	750	dredge[d]
1	0.15	1	medium-high to high (380–1,500)	1,200	dredge[d]/MNR
7	1.45	4	medium-high to high (380–1,500)	1,300	dredge[d]
17	3.7	11	high (900–1,500)	1,300	dredge[d]
18	3.8	11	very high (> 1,500)	1,900	dredge[d]
3	0.6	3	very high (> 1,500)	3,000	dredge
Summary of candidate cPAH sampling areas:			**Mean = 574 µg/kg Range = 13 to 3,000 µg/kg**		-
cPAH TEQ in site-wide ENR/MNR areas:			**Mean = 273 µg/kg Range = 4.3 to 1,900 µg/kg**		-

[a] This table is ordered by increasing cPAH TEQ.

[b] Values for samples collected within conceptual cPAH sampling areas (or within 20 ft of these areas) were included. Samples collected outside of the intertidal clam collection areas were excluded.

[c] No data were available within the proposed area; the closest sample had a cPAH TEQ of 520 µg/kg dw.

[d] Some sampling areas are in dredge areas (per Figure 18 in the ROD) to ensure the collection of a sufficient range of cPAH concentrations.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
ENR – enhanced natural recovery
J – estimated concentration
LDW – Lower Duwamish Waterway
MNR – monitored natural recovery
na – not available
RI – remedial investigation
RM – river mile
ROD – Record of Decision
TEQ – toxic equivalent
U – not detected at given concentration

2.2.3.2 Sample collection at each sampling area

At each of the sampling areas circled on Maps 2 and 3, samples for the cPAH porewater investigation will be collected during the baseline clam tissue collection effort (Windward and Integral 2017). The exact cPAH sampling locations within each area will be identified in the field based on clam density, such that sufficient clam tissue (e.g., five clams) can be collected from as small an area as possible. Sufficient co-located sediment will also be collected and composited (one composite for each area) to allow for bulk sediment and *ex situ* porewater measurements of selected composite samples. The quantity of clams and sediment needed for this evaluation will be specified in the clam tissue QAPP. The clam composite samples will be analyzed for cPAHs and lipids, and the sediment composite samples will be analyzed for cPAHs, total organic carbon (TOC), and black carbon.

2.2.3.3 Sample selection for ex situ porewater analysis

In order to select which sampling areas will be included in the porewater analysis, clam tissue and sediment collected from each area will be analyzed for cPAHs with a one-week turnaround time.[17] All 20 sediment samples collected will be processed for passive sampling and placed on the shaker at the laboratory to initiate *ex situ* exposure. The *ex situ* exposures will be completed for all sediments. When exposure is complete, the passive samplers will be extracted and the extracts will be stored in sealed vials; sediment samples will be stored frozen.

The co-located tissue and sediment chemistry data will be evaluated to identify a minimum of 10 sediment samples for which the corresponding *ex situ* sample extracts will be analyzed. Samples will be selected in consultation with EPA to represent the range of cPAH TEQs in sediment and tissue (e.g., if two samples have similar tissue and sediment cPAH TEQs, individual cPAH distribution, and carbon content, one of these samples may be excluded). Sample extracts not selected for analysis will be held until approval of the data evaluation report.

2.2.3.4 Ex situ porewater evaluation

Concentrations of individual cPAHs in porewater will be measured using an *ex situ* method. Passive samplers (e.g., PE fibers) will be used to characterize freely dissolved cPAH concentrations to address DQO 1.

Agitating a sample *ex situ* will not affect cPAH partitioning or bioavailability. Natural benthic organisms actively move around in the bioactive zone, causing sediment and porewater to mix naturally. *Ex situ* sampling will not capture the effects on porewater of groundwater upwelling, bioirrigation, or tidal pumping that would be taken into account when using *in situ* passive sampler deployments (Apell and Gschwend 2016). However, any effects from those factors on the sediment concentrations in the samples

[17] TOC and black carbon will also be analyzed with a one-week turnaround time.

will already have been captured. Also, as *ex situ* measurements are not affected by tidal pumping, bioirrigation, or groundwater, they have the advantage of more accurately representing the sorptive characteristics of the sediment. In general, *in situ* measurements may be better suited to estimate contaminant fluxes from the sediment into the water column, but *ex situ* measurements can provide a more accurate representation of sediment contributions to porewater concentrations.

Details regarding the methodology for conducting this *ex situ* evaluation (e.g., type of passive sampling and duration of laboratory test) will be presented in the clam tissue QAPP. This is because the sediment samples to be used for this evaluation will be collected at the same time and location as the clam tissue samples.

3 Baseline Porewater Concentrations in MNR and ENR Areas for PCBs and Dioxins/Furans

The third amendment to the AOC (EPA 2016) specifies the collection of baseline porewater samples from the biologically active zone in ENR/MNR areas. This section provides a systematic review of existing porewater information for PCBs and dioxins/furans to determine if additional baseline porewater data are needed as part of the pre-design studies, per LDW pre-design study porewater DQO 2.

3.1 PCBs

Passive samplers have been used throughout the LDW to collect porewater data for PCBs (Map 4). Three investigations have been conducted in the LDW to assess PCB concentrations in porewater (Table 3-1). In 2012, Dr. Philip Gschwend's group at MIT, using both *in situ* and *ex situ* passive samplers, measured PCB concentrations in porewater at five sites throughout the LDW (Apell and Gschwend 2016). In 2014, the MIT group deployed 52 *in situ* samplers; samplers were recovered at 20 locations to estimate porewater and overlying surface water concentrations (Map 4).

Table 3-1. Summary of LDW-specific sediment and porewater data

Study	Concentration of Total PCBs in Sediment[a] (µg/kg dw)				Concentration of Total PCBs in Porewater[a] (ng/L)			
	n	Mean	Min.	Max.	n	Mean	Min.	Max.
MIT 2012 Porewater Investigation	8	109	72[b]	144[b]	10[b] (*in situ*)	1.1	0.5	1.4
					5 (*ex situ*)	1.7	1.4	2.2
MIT 2014 Porewater Investigation	0	nc	nc	nc	20	not yet available	not yet available	not yet available
ENR/AC Pilot Study Baseline Dataset (2016)	18	178	17	468	12 (*in situ*)[c]	20.0	1.2	75
					6 (*ex situ*)[c]	71.7	26	150
RI/FS ENR/MNR Areas	672	120	2.2	790	0	na	na	na

[a] Total PCB data for sediment represent both Aroclor and PCB congener summations, as available; whereas the total PCB data in porewater represent PCB congener summations only. The PCB concentrations in the MIT investigations are the sum of 35 congeners or co-eluting groups of congeners. The PCB concentrations in the ENR/AC pilot study preliminary dataset are the sum of 209 PCB congeners. The PCB concentrations in the RI/FS ENR/MNR areas are the sum of PCB Aroclors.

[b] Two replicate measurements at each of the five locations.

[c] Porewater PCB concentrations were measured using SPME fibers placed *in situ* in the scour and intertidal plots (deployed for approximately 5.5 weeks) and *ex situ* in the subtidal plot (exposed in laboratory for approximately 7 weeks). The porewater PCB concentrations in the MIT study were measured using PE strips.

AC – activated carbon
dw – dry weight
ENR – enhanced natural recovery
LDW – Lower Duwamish Waterway
MIT – Massachusetts Institute of Technology
MNR – monitored natural recovery
n – sample count
na – not applicable
nc – not collected
PCB – polychlorinated biphenyl
RI/FS – remedial investigation/feasibility study
SPME – solid-phase microextraction

PCB concentrations in porewater were also measured as part of the ENR/AC Pilot Study (AMEC et al. 2016); passive samplers were used at three 1-ac plots (total of 18 samples) representing intertidal and subtidal conditions in the LDW (Map 4). These concentrations reflect baseline conditions prior to the application of an ENR sand layer, both with and without AC.

The PCB concentrations in sediment associated with the 2012 MIT and the ENR/AC porewater datasets ranged from 72 to 468 µg/kg dw, which is representative of the majority of the sediment PCB concentrations in ENR/MNR areas (Table 3-1).

3.1.1 MIT porewater sampling studies

PE passive samplers were deployed *in situ* at five locations in the LDW in November 2012. All of the study locations were within ENR/MNR areas (Maps 1 and 4). Sediment samples were collected by divers at these locations as they deployed the passive samplers in order to conduct an *ex situ* porewater characterization for the same sites.

The *in situ* samplers were retrieved in January 2013. PCB concentrations in sediment from the sampled areas ranged from 72 to 144 µg/kg dw[18] (Gschwend 2013). PCB concentrations in porewater were measured by analyzing PCB congener concentrations in the passive samplers, and by using the congener-specific polymer-water partition coefficients to calculate freely dissolved concentrations for 35 congeners or groups of co-eluting congeners (Apell and Gschwend 2016). PCB congener concentrations in porewater were also measured based on an *ex situ* analysis, in which five sediment samples from the same locations as the *in situ* samplers were tested for porewater using PE passive samplers in the laboratory.

PCB congener concentrations in porewater based on *in situ* and *ex situ* porewater sampling generally agreed within a factor of two (Apell and Gschwend 2016). *Ex situ* concentrations (based on the PE strips tumbled with the bulk sediment for two months) were consistently higher than *in situ* porewater concentrations (Apell and Gschwend 2016). The relationship between sediment and porewater concentrations in both *in situ* and *ex situ* samples was not evaluated, because the PCB and porewater concentrations were similar at all five locations.

As part of MIT's second investigation (conducted in summer/fall 2014), PE samplers were deployed and retrieved from 20 locations throughout the LDW to characterize PCB concentrations in porewater and overlying surface water, and to evaluate PCB fluxes[19] between sediment and surface water (Map 4). These samplers were placed in

[18] The PCB concentrations represent the sum of 35 congeners or co-eluting groups of congeners that represent approximately 85% of the total PCB concentration (sum of 209 congeners) in their sediment samples, which were also analyzed for all 209 PCB congeners (Apell and Gschwend 2016). The representativeness of the 35 congeners or co-eluting groups of congeners was not assessed for the porewater samples.

[19] MIT used the Environmental Fluid Dynamics Code (EFDC) model for this exercise.

MNR, ENR, dredge, and dredge/cap areas, as well as the Duwamish Diagonal early action area, which was remediated in 2005 (Map 4). The samplers were partially inserted into the sediment to enable sampling of the surface water immediately overlying the sediment bed as well as the sediment porewater. Co-located sediment samples were not collected as part of this effort. The porewater and overlying water data from the 2014 investigation are not yet available; they will be evaluated for use in the baseline porewater dataset once they are available.

3.1.2 Enhanced natural recovery/activated carbon pilot study

The Lower Duwamish Waterway Group (LDWG) is currently conducting a pilot study to evaluate the potential effectiveness of granular AC in combination with an ENR sand layer relative to an ENR sand layer alone in reducing the bioavailability of PCBs in LDW sediment (AMEC et al. 2015). The study locations include an intertidal plot, a subtidal plot, and a scour plot to enable the evaluation of AC added to an ENR layer over a range of conditions (Maps 1 and 4). Each of the study plots has been divided into two subplots of approximately 0.5 ac each: one ENR-only subplot and one ENR plus AC subplot.

In order to establish baseline conditions in each of the study locations, PCB concentrations (based on 209 PCB congeners), TOC, and black carbon were analyzed in sediment composite samples. Porewater PCB concentrations were measured using solid-phase microextraction (SPME) fibers placed *in situ* in the scour and intertidal plots (deployed for approximately 5.5 weeks) and *ex situ* in the subtidal plot (exposed in laboratory for approximately 7 weeks). The use of *ex situ* methods for the subtidal plots was the result of sediment disturbance from boat traffic experienced in these plots during the pilot study. As a result of the disturbance, only a few of the SPME fibers deployed in these plots were recovered, and it was necessary to use alternate methods (i.e., *ex situ* rather than *in situ*). A total of 18 composite samples[20] were analyzed for PCBs, TOC, and black carbon in sediment and PCBs in porewater.

3.1.3 Equilibrium partitioning evaluation

The relationship between PCB concentrations in sediment and porewater can be evaluated by comparing measured porewater concentrations to predicted porewater concentrations based on sediment concentrations and equilibrium partitioning models. Equilibrium partitioning models have been developed to predict porewater concentrations from PCB sediment concentrations and the fractions of organic carbon (OC) in sediment.

[20] Three composite samples were created to characterize each of the six 0.5-ac subplots. Eighteen passive samplers were deployed in each subplot, and three composites were created to characterize the entire subplot. Each composite contained six SPMEs.

The relationship between the PCB concentrations in sediment and porewater based on TOC is a one-carbon partitioning model (Equation 1).

$$C_S = (f_{OC}\ K_{OC}\ C_W) \qquad \textbf{Equation 1}$$

Where:

C_S = bulk sediment concentration

f_{OC} = fraction of organic carbon in the sediment

K_{OC} = organic carbon-to-water partition coefficient

C_W = freely dissolved concentration

This one-carbon model does not account for the more strongly sorbing black carbon phases in sediments, and therefore does not account for the variations in the sorptive properties of sediments encountered in urban waterways. EPA (2012) provides guidelines on how to account for these differences by adding an additional black carbon phase to the model, as proposed by Accardi-Dey and Gschwend (2002) (Equation 2).

$$C_S = (f_{OC}\ K_{OC}\ C_W) + (f_{BC}\ K_{BC}\ C_W^n)$$ **Equation 2**

Where the additional terms are defined as:

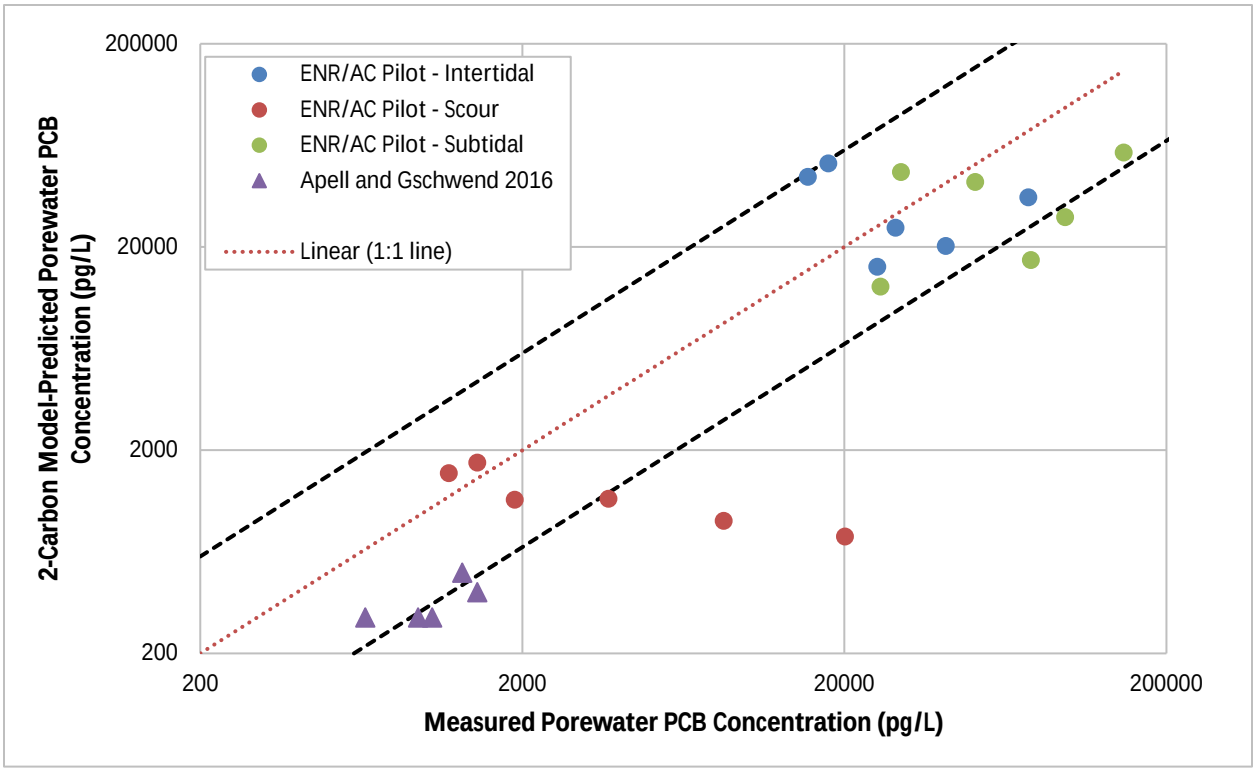
f_{BC} = fraction of black carbon in the sediment

K_{BC} = black carbon to water partition coefficient

n = Freundlich exponent describing sorption non-linearity to black carbon

Various definitions are available to differentiate among the different types of carbon discussed herein (i.e., OC, activated carbon, and black carbon). Black carbon is generally comprised of charcoal, soot, pitch, or other coal-based industrial byproducts, while OC is typically comprised of natural detritus and organic matter from the environment. Activated carbon is a form of black carbon that has been industrially processed (e.g., to enhance surface area and sorption capacity) and is made predominantly from coal or coconut shell.

The PCB concentrations measured in porewater by Apell and Gschwend (2016) and as part of the ENR/AC pilot study were compared to porewater concentrations predicted using a two-carbon equilibrium partitioning model. There is reasonable agreement between the measured and modelled results, with 65% of the modelled total PCB concentrations within a factor of three of the measured results (Figure 3-1).



Note: The modelled (predicted) results were calculated for each study by the study authors. The OC and black carbon partition coefficients used by the two studies differed. The measured and modelled PCB concentrations for the ENR/AC pilot study represent the sum of 209 congeners. For the MIT study, the measured and modelled concentrations are based on the 35 congeners and co-eluting groups of congeners (Apell and Gschwend 2016). The dotted black lines represent a factor of 3 in either direction of the 1:1 reference line.

Figure 3-1. Measured total PCB concentrations in the 2012 MIT study and the ENR/AC pilot study relative to predicted total PCB concentrations in porewater

3.1.4 Data gap evaluation

Available sediment and porewater data that have been collected from the LDW include data from the following efforts:

- **2012 MIT and ENR/AC pilot studies** – Co-located sediment and porewater data from 11 locations characterized by 23 samples[21] within the LDW were analyzed for PCBs; the locations were distributed throughout the waterway.
- **2014 MIT study** –Porewater data (without co-located sediment data) were collected from 20 locations and analyzed for PCBs.

In addition to the available porewater dataset, porewater concentration predictions are available from two-carbon modelling (Equation 2). The model performed reasonably

[21] Five locations were sampled as part of the 2012 MIT investigation and 6 subplots (each characterized by 3 composite samples for a total of 18 samples) were sampled as part of the ENR/AC pilot.

well over the range of PCB concentrations in ENR / MNR areas (Figure 3-1). However, to improve the model's ability to predict porewater concentrations from bulk sediment concentrations, an *ex situ* evaluation will be conducted for PCBs (similar to the evaluation described in Section 2.2.3 for cPAHs). An overview of this evaluation is presented in Section 3.1.5; additional details will be presented in the sediment QAPP. This is because the sediment samples to be used in the *ex situ* PCB porewater analysis will be collected during the sediment sampling event scheduled for February 2018. This evaluation will enable an assessment of the sorptive characteristics of site sediments and the refinement of one- or two-carbon models with site-specific partition constants. If the performance of the model is adequate, it will be used in the future to predict PCB porewater concentrations from bulk sediment data. To facilitate the modeling, TOC and black carbon will be analyzed in all baseline 0–10-cm surface sediment composite samples.

3.1.5 PCB investigation

Similar to the investigation proposed for cPAHs (Section 2.2.3), as part of the pre-design studies for the LDW, a PCB porewater investigation will be conducted to help address DQO 2. In this investigation, PCB concentrations in co-located sediment and porewater samples will be analyzed to better predict PCB concentrations in porewater. An overview of the proposed study design is provided in Figure 3-2 and discussed in the subsections that follow.

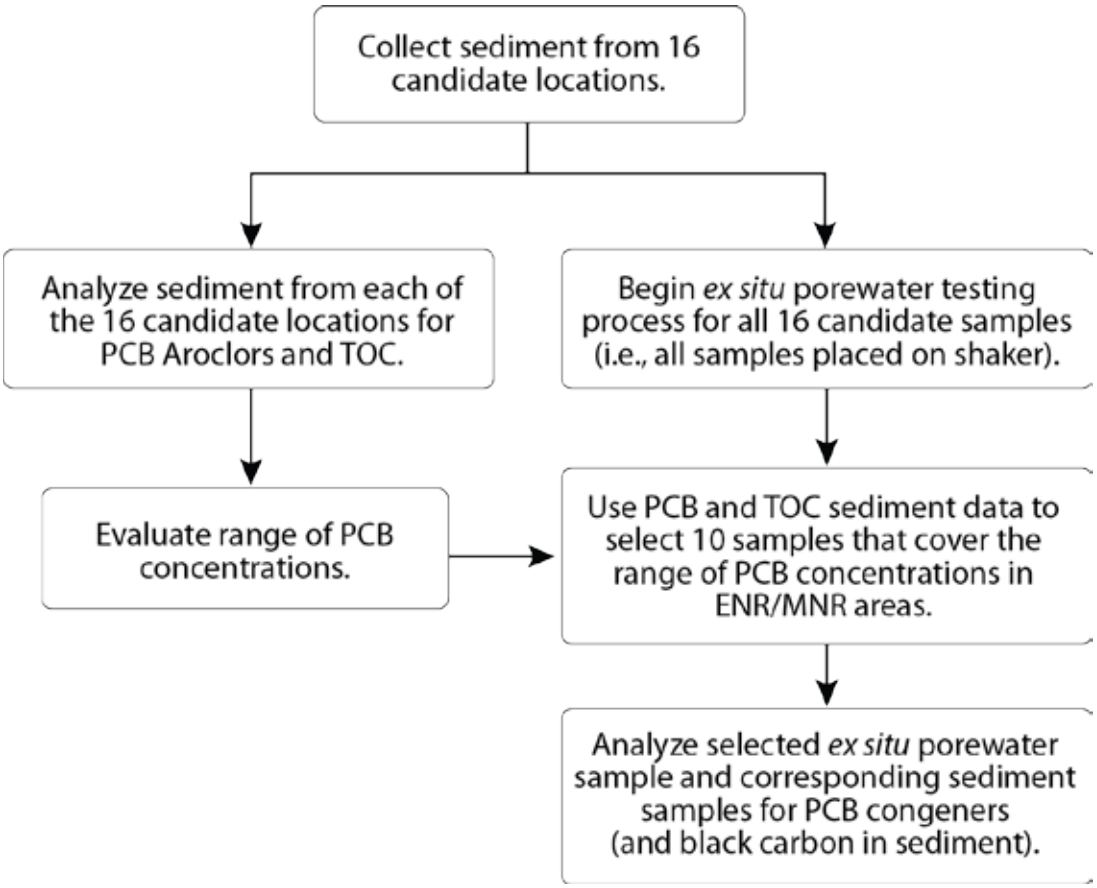


Figure 3-2. Conceptual PCB porewater sampling design

3.1.5.1 Selection of candidate sampling locations

Candidate sampling locations were selected to be consistent with surface sediment sampling locations proposed in the Work Plan (Windward and Integral 2017). These locations (summarized in Table 3-2 and shown on Map 5) include the 10 fixed individual locations in MNR areas selected to re-occupy locations with Washington State Sediment Management Standards (SMS) exceedances in the RI/FS dataset. Six additional locations were identified based on their PCB concentrations in order to widen the potential range of PCB concentrations, since the highest PCB concentration among the 10 fixed SMS locations was 340 µg/kg.

Table 3-2. Candidate locations for PCB *ex situ* porewater evaluation in order of increasing estimated PCB concentrations

Location Name	Conceptual Location Area	RM	Location Type	Sample Year	Total PCBs (µg/kg dw)	TOC (% dw)	Area Type
WRC-SS-B3	105	2.5	fixed (re-occupy SMS exceedance)	2004	18	0.472	MNR
DR276	168	5.0	fixed (re-occupy SMS exceedance)	1998	32	1.51	MNR
DR258	139	3.9	fixed (re-occupy SMS exceedance)	1998	62	1.55	MNR

Location Name	Conceptual Location Area	RM	Location Type	Sample Year	Total PCBs (µg/kg dw)	TOC (% dw)	Area Type
DR092	76	1.6	fixed (re-occupy SMS exceedance)	1998	64	0.70	MNR
DR010	26	0.6	fixed (re-occupy SMS exceedance)	1998	74	1.40	MNR
WIT270	118	3.0	fixed (re-occupy SMS exceedance)	1997	100	0.52	MNR
DR005	18	0.3	fixed (re-occupy SMS exceedance)	1998	168 J	2.30	MNR
DR290	157	4.5	fixed (re-occupy SMS exceedance)	1998	170	4.01	MNR
DR111	90	2.1	fixed (re-occupy SMS exceedance)	1998	311	2.26	MNR
				2004	176	2.84	
AN-028	136		fixed (new to extend PCB range)	2006	250	1.64	dredge
WIT288	45	0.7	fixed (re-occupy SMS exceedance)	1997	340	1.66	MNR
LDW-SS321	61	1.0	fixed (new to extend PCB range)	2006	450	1.43	partial dredge & cap
DR083	36	0.7	fixed (new to extend PCB range)	1998	567	2.29	ENR
DUD040	27	0.6	fixed (new to extend PCB range)	1995	620	2.10	MNR
LDW-SS57	72	1.5	fixed (new to extend PCB range)	2005	750	1.73	dredge
LDW-SS312	30	0.6	fixed (new to extend PCB range)	2006	1,010	4.20	dredge

ENR – enhanced natural recovery
MNR – monitored natural recovery
na – not applicable
PCB – polychlorinated biphenyl
SMS – Washington State Sediment Management Standards

3.1.5.2 Sample collection and analysis for PCBs

Samples will be collected as part of the 0–10-cm surface sediment grab sampling effort, as described in Section 3.2.1 of the Work Plan (Windward and Integral 2017). A subsample of the sediment collected from each of the grab samples in the 16 locations shown in Table 3-2 will be used for the *ex situ* PCB porewater evaluation. These subsamples will be analyzed for PCB Aroclors and TOC with a one-week turnaround time. During this time, sediment samples for all 16 samples from passive samplers will be placed on the shaker at the laboratory to initiate *ex situ* exposure. The PCB Aroclor and TOC data will be evaluated to identify approximately 10 sediment samples that will be included in the *ex situ* porewater analysis. These 10 sediment samples, which will be selected in consultation with EPA to represent the range of PCBs in sediment in MNR/ENR areas, will be analyzed for PCB congeners and black carbon, and the extracts from the corresponding *ex situ* passive samplers will be analyzed for PCB congeners. Remaining sediment samples and porewater extracts will be archived.

3.1.5.3 Ex situ *porewater evaluation*

As described for cPAHs (Section 2.2.3.4), PCB concentrations in porewater will be measured in the selected samples using an *ex situ* method. Passive samplers (e.g., PE sheets) will be used to characterize freely dissolved PCB congener concentrations.

Details regarding the methodology for conducting this *ex situ* evaluation (e.g., type of passive sampling and duration of laboratory test) will be presented in the sediment QAPP.

3.2 DIOXINS AND FURANS

Dioxins/furans have not been analyzed in LDW porewater. Analysis would be difficult because passive sampling methods for dioxins/furans are not as established as those for PCBs and cPAHs. Specifically, consensus polymer-to-water partition coefficients for dioxin/furan congeners are not available in current guidance documents (Ghosh et al. 2014; EPA et al. 2017), because there are only a few studies in the peer-reviewed literature that present partition coefficients for a few of the dioxin/furan congeners. Whether this uncertainty is acceptable to achieve DQO 2, and whether the passive sampling methods provide the necessary analytical resolution (i.e., quantitation limits), is evaluated below.

3.2.1 Uncertainty in polymer-to-water partition constants

A group of 45 experts in passive sampling—including developers, users, and decision makers from academia, government, and industry—met in 2012 at a Society of Environmental Toxicology and Chemistry (SETAC) technical workshop to develop *Guidance on Passive Sampling Methods to Improve Management of Contaminated Sediments* (Parkerton et al. 2013). This effort resulted in the publication of six papers, including one providing practical guidance for the calibration and implementation of passive sampling methods (Ghosh et al. 2014). This guidance highlights how the polymer-to-water partition constant (K_{pw}) used to predict porewater concentrations from passive sampler concentrations is the most important parameter to calibrate when using passive sampling methods. The document also highlights the challenges of accurately measuring K_{pw} for hydrophobic organic contaminants, and the importance of using reliably determined published partition coefficients.

The experts evaluated the numerous studies available for PAHs and PCBs, and were able to reach consensus on reliable partition coefficients for PAHs and PCBs for the more commonly used polymers in passive sampling: PE, polyoxymethylene (POM), and polydimethylsiloxane (PDMS) (Ghosh et al. 2014). The literature on dioxins/furans was deemed too sparse to recommend reliable partition constants for any of these three polymers. Similarly, recent EPA guidance does not include consensus partition constants for dioxins/furans, as "available data sets are limited and do not allow the designation of consensus provisional partition coefficients values at this time" (EPA et al. 2017). Instead, the limited partition constants available in existing studies are discussed in an appendix, and no assessment of their accuracy is provided (EPA et al. 2017, see Appendix B). Predictions of porewater dioxin/furan concentrations using passive sampling approaches are thus still in development. For example, two ongoing Strategic Environmental Research and Development Program (SERDP) initiatives have recently been completed but have yet to be fully developed for use in the field. These

initiatives aim to improve detection limit (DL) and equilibration challenges when using passive samplers to measure hydrophobic organics such as dioxins/furans (Lohmann and Khairy 2016; Ghosh et al. 2016).

3.2.2 Uncertainties in measurement

Bulk sediment concentrations of dioxin/furan congeners are relatively low in LDW ENR/MNR areas, with dioxin/furan TEQs ranging from 0.341 to 23.4 ng/kg. Detecting dioxins/furans in porewater using passive sampling would be challenging in this sediment concentration range. In addition, long deployment times would be needed, as dioxin/furan congeners are generally more hydrophobic than PCBs and PAHs, and equilibration time increases with increasing K_{OW} (Hawthorne et al. 2011). Based on sampling results for PCB congeners of equivalent chlorination levels in Bremerton, Washington, hepta- and octa-chlorinated dioxins would achieve only 15 to 25% equilibration after one month of deployment (SPAWAR Systems Center Pacific et al. 2017; AMEC et al. 2016). Deployment times would therefore need to be extended, increasing the chance of sampler loss, and equilibrium corrections would still be significant, adding to measurement uncertainty (Ghosh et al. 2014).

Given the equilibrium and DL issues that would be encountered *in situ*, a passive sampling approach to determine dioxin/furan concentrations in porewater would have to be conducted *ex situ*. Agitation *ex situ* would help resolve equilibration issues, and large polymer masses could be used to reduce DL problems. However, as a general rule, a ratio of 1:100 polymer mass-to-sediment OC mass is needed in *ex situ* equilibration studies (Ghosh et al. 2014), so the study would require large quantities of well-homogenized sediment. Preliminary calculations suggest that in theory this could be accomplished, but it would require the agitation of large volumes of sediment slurries per sample (at least 2 kg dw) to ensure robust detections of congeners.

Due to the large mass of polymer needed and its higher partition constants, PE would need to be used. Peer-reviewed PE-to-water partition constants are limited to a study by Adams et al. (2007), wherein a relationship between K_{PE} with K_{OW} was developed using eight PAHs, five PCBs, and one dioxin/furan congener. Therefore, dioxin/furan porewater concentrations measured using this relationship would be highly uncertain.

3.2.4 Data gaps evaluation

No porewater data exist for dioxins/furans in the LDW. Establishing dioxin/furan concentrations in porewater for ENR/MNR areas would require conducting an *ex situ* investigation with high uncertainty using LDW sediment, or predicting concentrations based on equilibrium partitioning models.

Given the needed scale of effort and uncertainty associated with analytical limits and K_{PE} values, it is recommended that baseline dioxin/furan concentrations in ENR/MNR areas be modeled instead of measured. Using LDW-specific sediment data, including TOC and black carbon measurements, dioxin/furan concentrations in ENR/MNR-area

porewater will be predicted using one- and two-carbon models. As discussed in Section 3.3.1, these models generally bracket the *in situ* porewater concentrations of hydrophobic chemicals. Measuring TOC and black carbon in baseline 0–10-cm sediment samples will provide an indication of potential differences in sediment sorptive properties and hence dioxin/furan partitioning in the LDW. Analytical technology limitations that impact the ability to directly measure concentrations of dioxins/furans in porewater to potentially improve predictive models, or to obtain baseline data, will be revisited during remedial design to determine if analytical technologies have improved.

4 Conclusions

In this addendum, two DQOs were established for porewater analyses based on the LDW ROD (EPA 2014) and the third amendment to the AOC (EPA 2016). This section presents a summary of how each of these DQOs were addressed for the four COCs (Table 4-1).

- **DQO 1** –Assess the relationship between concentrations of arsenic and cPAHs in clam tissue, porewater, and sediment to help evaluate whether achieving sediment cleanup levels for these COCs will reduce concentrations in clam tissue to TTLs.
- **DQO 2** – Estimate baseline porewater concentrations in MNR/ENR areas for PCBs and dioxins/furans. This DQO is primarily intended to help assess the effect of reduced sediment concentrations on biota exposure and tissue concentrations.

Table 4-1. Summary of DQO conclusions

DQO	COC	Conclusions
DQO 1 – Assess the relationship between concentrations of arsenic and cPAHs in clam tissue, porewater, and sediment to help evaluate whether achieving sediment cleanup levels for these COCs will reduce concentrations in clam tissue to TTLs.	arsenic	No additional data needed.
	cPAHs	*Ex situ* cPAH porewater evaluation will be conducted for a minimum of 10 sediment samples (starting with 20 candidate locations) that span the range of cPAH concentrations in ENR/MNR areas.
DQO 2 – Estimate baseline porewater concentrations in ENR/MNR areas for PCBs and dioxins/furans. This DQO is primarily intended to help assess the effect of reduced sediment concentrations on biota exposure and tissue concentrations.	PCBs	*Ex situ* PCB porewater evaluation will be conducted for 10 sediment samples (starting with 16 candidate locations) that span the range of PCB concentrations in ENR/MNR areas.
	dioxins/ furans	Use of passive samplers to measure porewater dioxin concentrations is not sufficiently reliable at this time. The need for measurement and/or modeling for dioxins/furan baseline in porewater will be revisited in the future.

COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
ENR/MNR – enhanced natural recovery/monitored natural recovery
DQO – data quality objective
PCB – polychlorinated biphenyl

DQO 1 was addressed as follows.

For arsenic, both the LDW RI (Windward 2010) and RARE (Kerns et al. 2017) studies found that a moderate relationship exists between total arsenic in sediment and inorganic arsenic in clam tissue, and both studies concluded that other factors were likely also important in influencing the bioaccumulation of inorganic arsenic. The RARE

study demonstrated that concentrations in porewater were related to those in sediment, and that the porewater data did not help to explain the variance around the clam tissue-sediment relationships. Thus, no further porewater data are proposed for arsenic.

For cPAHs, the LDW RI (Windward 2010) and the available literature suggested that the relationship between cPAH TEQs in sediment and clam tissue is either weak or nonexistent, indicating that non-sediment factors are important for understanding cPAH bioaccumulation. Based on the available data in the LDW RI and on information in the literature, it is unknown whether porewater data would be helpful in further understanding the clam tissue-sediment relationship. To address DQO 1, co-located surface sediment, clam tissue, and *ex situ* porewater will be analyzed for cPAHs to evaluate the potential relationships between clams and sediment.

Regarding DQO 2, which is primarily intended to help assess the effect of reduced PCBs and dioxins/furans concentrations in sediment on biota exposure and tissue concentrations, the following conclusions were drawn.[22]

For PCBs, co-located sediment and porewater data have been analyzed from 11 locations throughout the waterway. In addition, porewater data (without co-located sediment data) have been collected from 20 locations and analyzed for PCBs as part of the 2014 MIT study. Combined, these data represent 31 locations for which PCB porewater data are available. In addition, estimated porewater concentrations can be predicted using the two-carbon modelling that has been conducted for the LDW. However, to improve the model's ability to predict porewater concentrations from bulk sediment, an *ex situ* porewater evaluation will be conducted with a subset of sediment samples that span the range of PCB concentrations in the ENR/MNR areas.

No baseline porewater data exist for dioxins/furans in the LDW. Because passive sampler partitioning coefficients for dioxins/furans are still in development and DLs may also be an issue for the LDW, baseline data for dioxin/furan congeners in porewater will be predicted using models similar to those used for PCBs and PAHs.

[22] Arsenic and cPAHs were not included in DQO 2 for the following reasons. For arsenic, LDW-specific data are available from the RARE study (Kerns et al. 2017), and these data have provided a porewater-sediment relationship for a range of sediment concentrations. This range is similar to the range of concentrations in ENR/MNR areas. Thus, no additional porewater data are proposed for arsenic. In contrast, no LDW-specific porewater data are currently available for cPAHs. As discussed for DQO 1, LDW-specific co-located sediment and porewater data will be collected for a range of cPAH TEQs representative of ENR/MNR areas. These data will be used to test the two-carbon model in the LDW, and assuming it is sufficiently predictive, if additional porewater concentrations are needed in ENR/MNR areas, they will be modelled.

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APPENDIX F. CLAM SAMPLING RESULTS FOR cPAH ANALYSIS OF SIPHON SKIN

MEMORANDUM

To: Elly Hale, EPA
From: Windward on behalf of LDWG
Subject: Clam sampling results for cPAH analysis of siphon skin
Date: August 7, 2017

As discussed in the Lower Duwamish Waterway (LDW) human health risk assessment (HHRA) and remedial investigation (RI) (Windward 2007, 2010), at least 95% of the risk to human health from arsenic and carcinogenic polycyclic aromatic hydrocarbons (cPAH) associated with seafood consumption is from the consumption of clams. The Regional Applied Research Effort (RARE) study conducted in the LDW found that inorganic arsenic concentrations detected in siphon skin (19.0 to 65.0 mg/kg wet weight [ww]) were significantly higher than those detected in main-body tissue (0.02 to 0.09 mg/kg ww) (Kerns et al. 2017). However, no information was obtained regarding the relative cPAH toxic equivalents (TEQs) in siphon skin and main-body clam tissue.

Thus, in order to determine if significant differences exist between cPAH TEQs in clam siphon skin and those in main-body clam tissue (as was the case for inorganic arsenic), clams were collected from three areas in the LDW. These clams were sent to Analytical Resources, Inc. (ARI) for cPAH analysis of siphon skin and main-body clam tissue; this memorandum summarizes the resultant data. This information allows for a determination of whether siphon skins should be analyzed separately from whole-body tissue in the baseline clam tissue investigation proposed in the Work Plan (Windward and Integral 2017).

FIELD COLLECTION

Softshell clams (*Mya arenaria*) were collected during low tide on June 26, 2017 per the sampling memo (Attachment 1). Three sampling areas were targeted for the collection of clams based on the clamming areas identified in the RI (clamming area 3, northern clamming area 11N, and southern clamming area 11S) (Map 1). However, the field crew was unable to find sufficient clams in clamming area 3, so clamming area 6 was selected as an alternative location. The target and actual clamming areas are described in Table 1 and shown on Map 1. The majority of clams were collected near the low tide line.

Table 1. Clam collection areas

Clamming Area	RM	No. of Clams Collected	Description of Substrate/Area
Clamming area 3	0.6 (west side of waterway)	0	The top 10 cm were unconsolidated silt and fine sand, with anoxic, hard-packed fine sand and silt below that. Brick debris was observed near the surface with wood debris below.
Clamming area 6	2.1 (west side of waterway)	20	fine to medium sand with some silt; approx. 30 ft of beach.
Clamming area 11 (north)	3.8 (east side of waterway)	19	silt and fine sand; some cobble; approx. 50 ft of beach.
Clamming area 11 (south)	3.8 (east side of waterway)	20	silt and fine sand; approx. 50 ft of beach.

RM – river mile

Upon completion of the sampling effort, all of the *M. arenaria* clams were transported and stored, refrigerated at < 6°C, overnight at Windward Environmental LLC (Windward) prior to transport to ARI.

LABORATORY PROCEDURES

Removal of the clam tissue from the shell and separation of the siphon skin from the main body of the clam were performed at ARI on June 27, 2017. Technicians wore powder-free, nitrile examination gloves, and used equipment that was cleaned (detergent wash, acid rinse, and deionized water rinse) between composite samples to avoid contaminating tissue samples during sample handling and processing.

Two composite samples (i.e., one siphon skin and one remainder tissue) were created from 15 clams collected from each site. Clams selected for tissue compositing and analysis were measured to confirm that they met the minimum width requirement of 2 cm prior to processing (Figure 1). Clams were rinsed with deionized water and opened, and all of the soft tissue was removed from the shell; the siphon skin was then carefully dissected from the main-body tissue. The individual siphon skin and remainder tissue samples were rinsed with deionized water and weighed prior to being placed in glass jars. The individual siphon skins and remainder tissues for each location were combined to create, respectively, a siphon skin composite sample and a remainder tissue composite sample for each location. Composites were homogenized by the laboratory and analyzed for the parameters listed in Table 2.

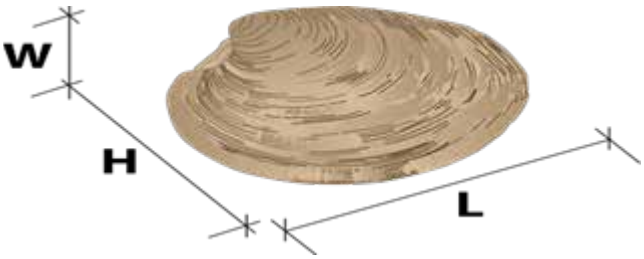

Figure 1. Clam dimension measurements

Table 2. Analytical methods

Parameter	Method	Reference
PAHs	GC/MS	EPA 3350-C Mod/EPA 8270D-SIM
Lipids	gravimetric extraction	Bligh and Dyer (mod)
Percent solids	drying oven	PSEP (1997)

EPA – US Environmental Protection Agency
GM/MC – gas chromatography/mass spectrometry
PAH – polycyclic aromatic hydrocarbon
PSEP – Puget Sound Estuary Program
SIM – selected ion monitoring

RESULTS

The average clam size and average tissue mass for each composite sample are provided in Table 3. The size of each individual clam and the mass of the tissue associated with that clam are provided in Attachment 2. The clams in all three composite samples were similar in size, which was measured as width of the shell and mass of the tissue. The average siphon tissue represented between 10 and 18% of the total clam tissue mass for the clams in each of the composite samples.

Table 3. Average clam size and average tissue mass for each composite sample

Sampling Location	No. of Clams in Composite	Average Clam Shell Width (cm)	Average Tissue Mass (g ww) (remainder)	Mean Siphon Tissue Mass (g ww)	Mean Siphon Tissue Mass as % Total Mass
C-6	15	3.00	14.99	2.45	10
C11N	15	2.94	17.23	3.82	18
C11S	15	2.80	15.64	2.91	16

ww – wet weight

Two tissue composite samples were created for each location, one composite of clam siphon tissue and one composite of remainder tissue, for a total of six tissue composite samples. Each of the six composite samples were analyzed for polycyclic aromatic hydrocarbons (PAHs). Detection frequencies and concentrations across all six composite

samples are summarized in Table 4. cPAH data for each composite sample are provided in Table 5, and results for all individual PAH compounds and PAH sums are provided in Attachment 2.

Table 4. Summary of PAH concentrations in clam tissue samples

Analyte	Detection Frequency	Minimum Detected Concentration (µg/kg ww)	Maximum Detected Concentration (µg/kg ww)	Minimum Reporting Limit (µg/kg ww)	Maximum Reporting Limit (µg/kg ww)
1-Methylnaphthalene	0/6	nd	nd	0.47	0.49
2-Methylnaphthalene	0/6	nd	nd	0.47	0.49
Acenaphthene	3/6	0.87	1.33	0.49	0.49
Acenaphthylene	0/6	nd	nd	0.47	0.49
Anthracene	6/6	0.50	1.34	na	na
Benzo(a)anthracene	6/6	1.84	6.80	na	na
Benzo(a)pyrene	6/6	2.10	5.86	na	na
Benzo(b)fluoranthene	6/6	2.97	7.20	na	na
Benzo(g,h,i)perylene	6/6	2.53	8.57	na	na
Benzo(j)fluoranthene	6/6	1.23	3.29	na	na
Benzo(k)fluoranthene	6/6	1.32	3.66	na	na
Chrysene	6/6	2.74	8.63	na	na
Dibenzo(a,h)anthracene	4/6	0.52 J	1.72 J	0.47	0.49
Dibenzofuran	3/6	0.51	0.73	0.49	0.49
Fluoranthene	6/6	4.85	20.3	na	na
Fluorene	3/6	0.89	1.39	0.49	0.49
Indeno(1,2,3-cd)pyrene	6/6	1.11	5.97	na	na
Naphthalene	0/6	nd	nd	0.56	0.59
Phenanthrene	6/6	1.56	7.12	na	na
Pyrene	6/6	4.63	16.9	na	na

J – estimated concentration
na – not applicable
nd – not detected
PAH – polycyclic aromatic hydrocarbon
U – not detected at given concentration
ww – wet weight

Table 5. cPAH TEQs in clam siphon and remainder tissue samples

Sample Name	Clam Tissue Sampling Location	Matrix	cPAH TEQ (ug/kg ww) (clam tissue)
LDW17-C06-MARM-Comp01	6	clam remainder	5.0 J
LDW17-C06-MAST-Comp01	6	siphon skin	3.0 J
Estimated whole-body concentration[a]			**4.8 J**
LDW17-C11N-MARM-Comp01	11 (north)	clam remainder	4.3
LDW17-C11N-MAST-Comp01	11 (north)	siphon skin	8.3
Estimated whole-body concentration[a]			**5.0**
LDW17-C11S-MARM-Comp01	11 (south)	clam remainder	3.5
LDW17-C11S-MAST-Comp01	11 (south)	siphon skin	5.1 J
Estimated whole-body concentration[a]			**3.8 J**

[a] Estimated whole-body concentration calculated based on mass-weighted average concentration. The average mass fractions of siphon skin and remainder tissue for each composite sample were used to calculate the estimated whole-body concentration for the composite.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
J – estimated concentration
TEQ – toxic equivalent
ww – wet weight

As shown in Table 5, cPAH TEQs in the siphon skin and remainder tissue composites were similar to each other in the three sampling areas, demonstrating that cPAHs are not being preferentially accumulated in siphon skin. In addition, the cPAH TEQs were similar across the locations, with TEQs ranging from 3.0 to 8.3 µg/kg ww in the two tissue types, and from 3.8 to 4.9 µg/kg ww in the estimated whole-body concentrations.

No sediment data were collected as part of this investigation. Based on RI data collected in the vicinity of the clam sampling areas (Map 1), cPAH TEQs in sediment samples closest to the clam collection locations ranged from 54 to 6,600 µg/kg dry weight (dw), with the lowest concentration associated with clamming area 6 and the highest concentration associated with clamming area 11 (Table 6). No RI clam tissue data are available for clamming area 11; clams collected in clamming area 6 had a cPAH TEQ of 10 µg/kg ww, relative to the cPAH TEQ of 4.7 µg/kg dw measured as part of this investigation.

Table 6. cPAH TEQs in clam tissue and sediment samples from the LDW RI

Clam Tissue Sampling Location	This investigation	Existing RI data (Windward 2010)	
	cPAH TEQ (ug/kg ww) in Clam Tissue	cPAH TEQ (ug/kg ww) in Clam Tissue	cPAH TEQ (ug/kg dw) in Surface Sediment
6	4.8 J	10	54–120 (n = 5)
11 (north)	5.0	na	1,500–1,800 (n = 2)
11 (south)	3.8 J	na	1,900–6,600 (n = 4)

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
J - estimated
LDW – Lower Duwamish Waterway
na – not available
RI – remedial investigation
TEQ – toxic equivalent
ww – wet weight

DATA QUALITY REVIEW

In lieu of formal data validation, the laboratory quality assurance (QA) results were reviewed. Samples were prepared and analyzed within recommended holding times. All sample analysis met laboratory and method QC limits and frequency requirements for blanks, laboratory control samples, replicates, and surrogate and spike recoveries. The initial and continuing calibrations met method requirements, with the exception of the initial calibration response for dibenzo(a,h)anthracene; the responses for dibenzo(a,h)anthracene were above the 120% window for calibration. The dibenzo(a,h)anthracene concentrations were qualified as estimated (i.e., J-qualified) as a result.

CONCLUSIONS

The cPAH TEQs in the clam siphon skin and remainder clam tissue composites were similar based on results from all three clam tissue sampling areas. The data indicate that cPAHs are not preferentially accumulating in siphon skin relative to remainder clam tissue. Therefore, composites of whole-body clam tissue that include siphon skin tissue will be analyzed for cPAHs in the upcoming baseline tissue sampling. The work plan and associated clam tissue quality assurance project plan (QAPP) will reflect this approach.

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ATTACHMENT 1. CLAM SAMPLING FOR cPAH ANALYSIS OF SIPHON SKIN MEMORANDUM

MEMORANDUM

To:	LDWG
From:	Windward
Subject:	Clam sampling for cPAH analysis of siphon skin
Date:	June 8, 2017

This memorandum documents the rationale and methods followed in the collection of clams from the Lower Duwamish Waterway (LDW) to assess the relative concentrations of carcinogenic polycyclic aromatic hydrocarbons (cPAHs) in the clam siphon skin relative to the remainder of the clam tissue (referred herein as "main body clam tissue").

PROJECT BACKGROUND AND OBJECTIVES

As discussed in the LDW human health risk assessment (HHRA) and remedial investigation (RI) (Windward 2007, 2010), 95% or more of the arsenic and cPAH risk to human health associated with seafood consumption is from the consumption of clams. The RARE study conducted in the LDW found that inorganic arsenic concentrations detected in siphon skin were significantly higher (19.0 to 65.0 mg/kg wet weight [ww]) than those detected in main body tissue (0.02 to 0.09 mg/kg ww) (Kerns et al. 2017). However, no information is available about the relationship between siphon skin and main body clam tissue for cPAHs.

Thus, in order to determine if there are significant differences in cPAH concentrations between clam siphon skin and main body clam tissue as was the case for inorganic arsenic, clams will be collected from three areas in the LDW with clam habitat and higher cPAH toxic equivalents (TEQs) in sediment. These clams will be sent to the Analytical Resources, Inc. (ARI) for cPAH analysis of siphon skin and main body clam tissue. If analysis of the samples indicates that there are significant differences between cPAH concentrations in clam siphon skin and main body tissue, siphon skin may be analyzed separately in the baseline clam tissue investigation proposed in the Work Plan (Windward and Integral 2017).

STUDY DESIGN AND SAMPLING METHODS

In order to maximize the sampling opportunity, the field crew will collect *Mya arenaria* clams around the low tide (-2.9 ft MLLW) at 1:24 pm on June 26, 2017. Up to 45 *M. arenaria* clams will be collected from two of the clam tissue sampling areas (Table 1) with higher sediment cPAH concentrations identified in Figure 1. Clamming area 3 is publically accessible from the shoreline, but the two locations in clamming area 11 may require access by boat.

Table 1. Clam collection areas

Clamming Area	RM	Coordinates[a]		Property Owner
		Easting (X)	Northing (Y)	
North portion of area 3	0.6 (west)	1265910	208275	Port of Seattle/, northern end of Terminal 107; (area publicly accessible)
North portion of area 11	3.8 (east)	1276041	194978	The Boeing Company, adjacent to Jorgensen Forge
South portion of area 11	3.8 (east)	1276104	194752	The Boeing Company

[a] Coordinates are North American Datum 1983, State Plane Washington North, US survey feet.

RM – river mile

MLLW – mean lower low water

A team with at least two individuals will spend up to 2 hours per location to collect 15 *M. arenaria* clams for analysis at each sampling location. If 10 clams of sufficient size are not collected after one hour, the area may be expanded further along the intertidal beach area while remaining in the area where higher sediment cPAH concentrations were identified. To collect clams, team members will focus their effort by digging for clams with a shovel where clam siphon holes ("shows") or other evidence of clam presence are observed.

Consistent with previous *M. arenaria* collection efforts for the LDW RI (Windward 2004), only intact (i.e., non-broken) clams ≥ 2 cm wide (as measured from valve to valve; Figure 2) will be retained to meet minimum tissue mass requirements for analysis. Broken clams will not be included in the sample. Upon collection, each retained clam will be rinsed in site water to remove any visible sediment and debris. Each clam will be individually wrapped in aluminum foil and all clams from a given area will then be placed in a re-sealable Ziploc bag and put on ice for transport to the laboratory.

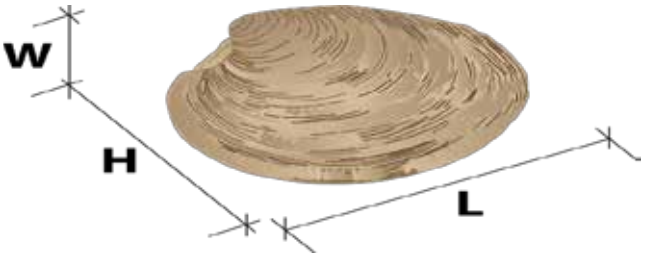

Figure 2. Clam dimension measurements

A Scientific Collection Permit has been obtained from Washington Department of Fish and Wildlife for the collection of these clams. For collection permit reporting purposes, the following data will be recorded on Form 1 (attached) or in the field logbook for each clam encountered, regardless of target species or size:

- Species
- Width (e.g., valve to valve) measurement
- Disposition (e.g., retained for analysis, released at capture site, broken shell)

In addition, a description of the area where clams were collected (including information about sediment type and approximate centroid coordinates) will be recorded on the field forms and/or in the field logbook.

LABORATORY PROCEDURES

Removal of the clam tissue from the shell and separation of the siphon skin from the main body of the clam will be performed at ARI. The technicians will wear nitrile powder-free examination gloves; all sampling equipment will be stainless steel, and will be cleaned between samples to avoid contaminating tissue samples during handling and processing. The laboratory will homogenize and composite siphon skin and main body clam tissue samples. Two composite samples (e.g., one siphon skin and one main body) from 15 clams will be created for each clamming area.

The six composite samples will be analyzed for PAHs using EPA 8270-SIM. Each tissue sample must have a minimum mass of 10g in order to achieve a reporting limit of 5 µg/kg for each PAH compound. Individual clam siphon skins collected as part of the RARE study had masses of 1g on average (K. Kerns pers comm. 2017). Therefore, 15 clams should provide sufficient mass for the clam siphon skin samples.

DATA REPORTING

When the data are available from ARI, they will be summarized in a brief memorandum and submitted to LDWG.

HEALTH AND SAFETY

Potential safety hazards associated with digging for bivalves at intertidal beaches and respective recommended personal protective equipment are discussed below.

Slips and trips

As with all fieldwork sites, caution should be exercised to prevent slips on slick surfaces. In particular, care should be taken on the shoreline or in rainy or wet conditions where slick rocks are found. Trips are also a hazard in the intertidal zone where uneven substrate is common.

Workers should wear water-resistant boots with good tread made of material that does not become overly slippery when wet.

Falling overboard

Intertidal beaches may be accessed from a boat. As with any floating platform, there is always a risk of falling overboard. Workers should exercise caution when boarding and departing from a vessel.

Each worker must wear a personal flotation device (PFD) when travelling on a boat. Boats will also be equipped with a life ring.

Sediment exposure

Previous sediment investigations have shown that some chemical substances may be present at higher-than-background concentrations in the sampling areas. Digging activities will increase the potential for skin exposure to potentially contaminated sediment. General field clothes are usually adequate to minimize exposure to sediment, but impermeable clothing such as rain gear may be worn as a supplement to protect clothing.

Chemical-resistant (e.g., nitrile) gloves will be provided to reduce exposure to workers' hands.

Back strain

Back strain can result if lifting is done improperly. During any manual handling tasks, including digging sediment with a shovel, workers should lift with the load supported by their legs and not their backs.

Emergency Routes to the Hospital

The name, address, and telephone number of the hospital that will be used to provide medical care is as follows (Map 1):

Harborview Medical Center
325 - 9th Avenue
Seattle, WA
206.323.3074

FORM 1. CLAM COLLECTION FORM

LOCATION:			**APPROX. AREA SIZE (FT X FT):**
DATE:			**SUBSTRATE DESCRIPTION:**
CENTROID COORDINATES:			
LAT.	**LONG.**		
START TIME:			**COMMENTS/NOTES:**
STOP TIME:			
CREW:			

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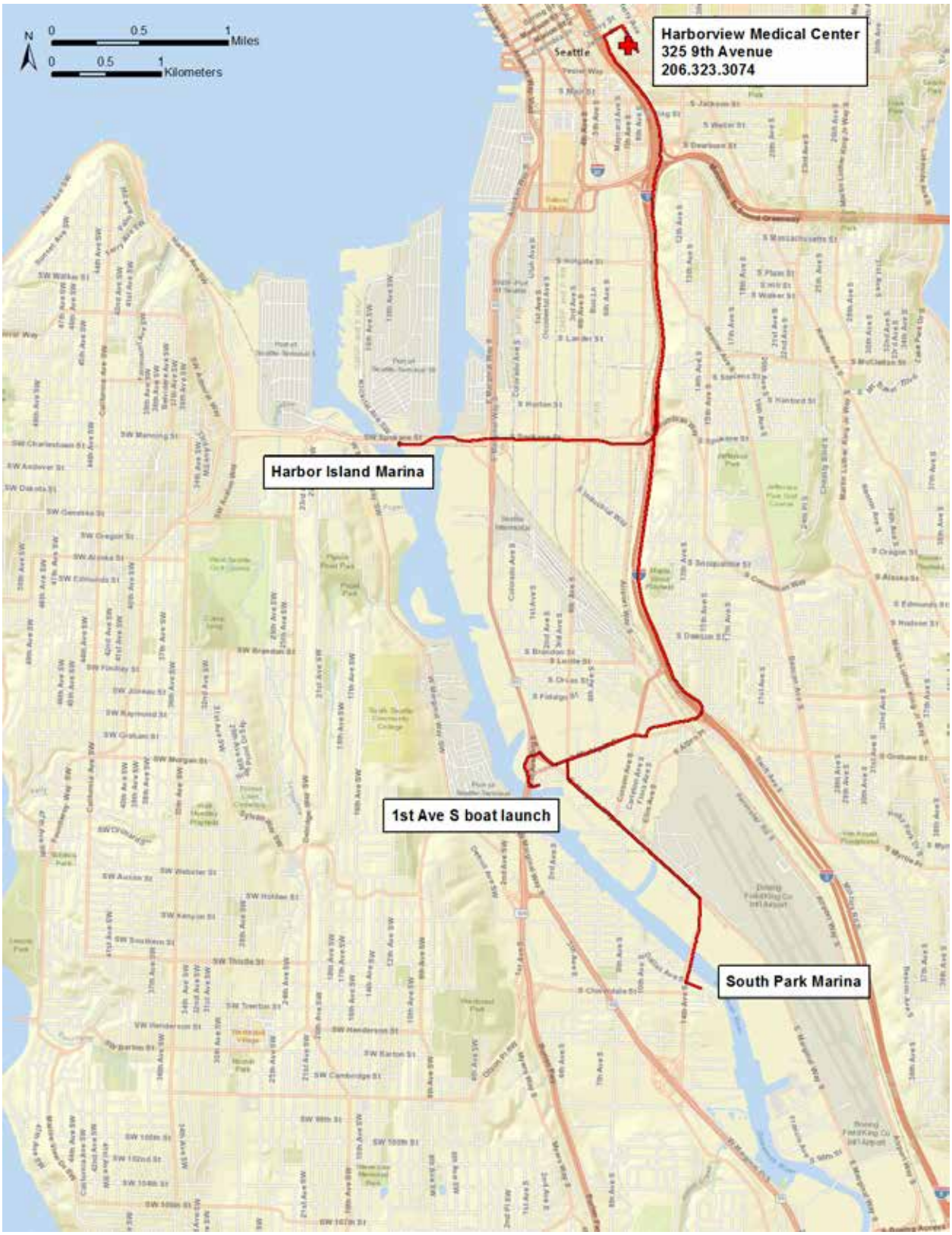

Map 1. Emergency routes to Harborview Medical Center

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Windward, Integral. 2017. Pre-design studies work plan. Draft. Windward Environmental LLC and Integral Consulting Inc., Seattle, WA.

ATTACHMENT 2. DATA TABLES

Table A1. Clam width and mass summary

Site Name	Clam No.	Width (cm)	Remainder Mass (g)	Siphon Skin Mass (g)
C06	1	3.1	12.57	2.69
C06	2	2.8	16.82	2.48
C06	3	3.0	12.38	2.65
C06	4	3.5	16.80	2.99
C06	5	3.1	15.71	2.54
C06	6	3.0	21.48	2.60
C06	7	3.3	15.27	2.55
C06	8	2.9	9.85	1.71
C06	9	2.9	14.26	1.82
C06	10	3.5	19.61	4.73
C06	11	3.1	18.97	2.39
C06	12	2.7	6.31	1.56
C06	13	2.6	9.92	1.49
C06	14	2.7	23.60	2.67
C06	15	2.8	11.34	1.87
C06 composite mass			**224.89**	**36.74**
C11N	1	3.1	16.04	5.66
C11N	2	2.4	11.25	2.52
C11N	3	2.7	8.74	2.41
C11N	4	3.4	21.42	4.35
C11N	5	2.9	13.88	3.60
C11N	6	3.1	14.54	2.86
C11N	7	3.4	32.70	8.33
C11N	8	3.1	20.95	3.74
C11N	9	3.0	16.69	5.02
C11N	10	2.8	26.44	4.21
C11N	11	2.5	8.42	1.63
C11N	12	3.1	14.71	2.93
C11N	13	2.9	25.72	3.82
C11N	14	2.7	11.46	2.94
C11N	15	3.0	15.46	3.34
C11N composite mass			**258.42**	**57.36**

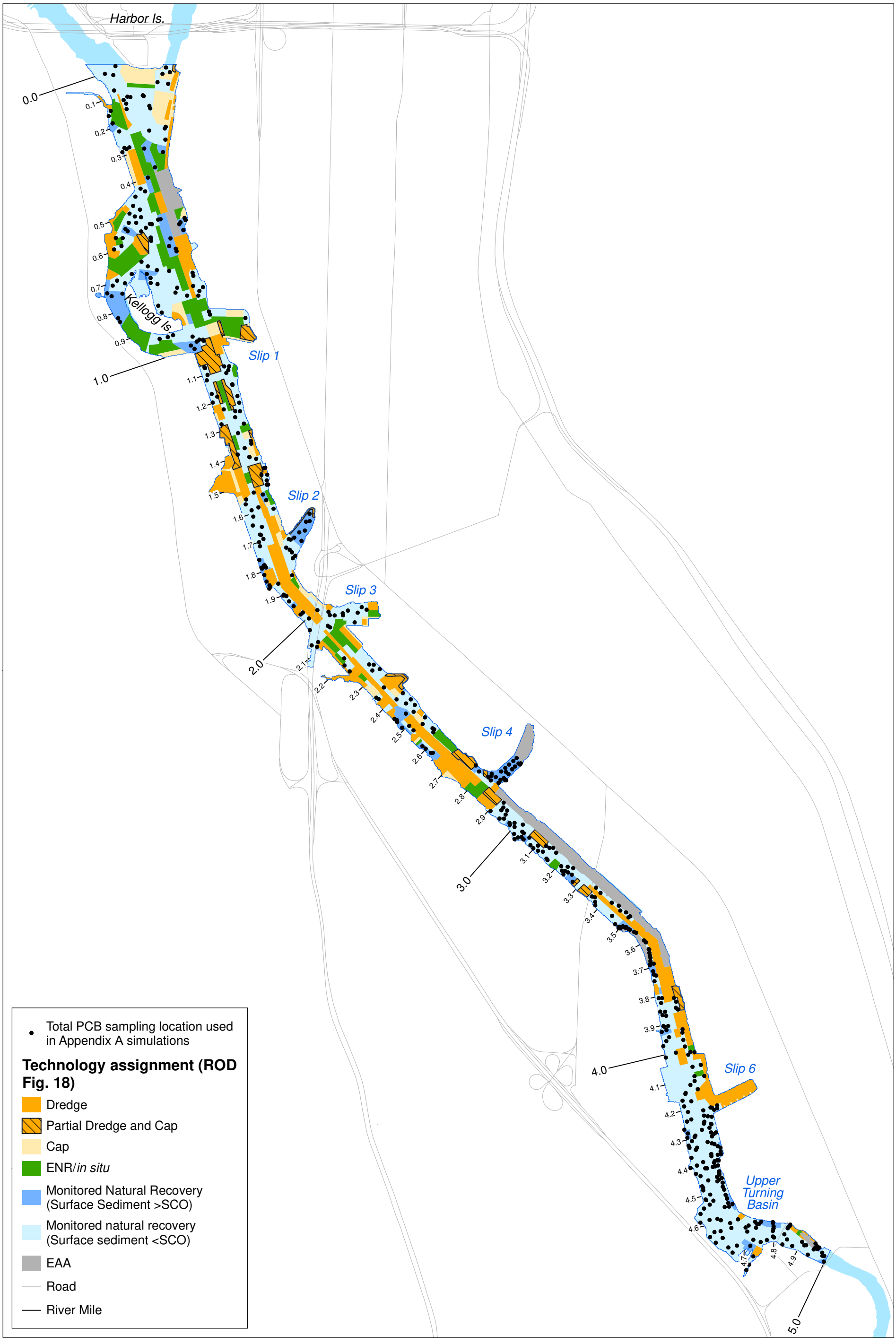
Site Name	Clam No.	Width (cm)	Remainder Mass (g)	Siphon Skin Mass (g)
C11S	1	2.6	18.47	2.77
C11S	2	2.9	14.00	2.38
C11S	3	2.3	16.24	2.42
C11S	4	3.1	15.04	4.08
C11S	5	2.6	11.49	2.09
C11S	6	2.9	16.04	4.29
C11S	7	2.2	14.18	2.7
C11S	8	3.0	13.96	2.67
C11S	9	3.3	18.32	3.28
C11S	10	2.6	17.20	1.83
C11S	11	2.4	8.73	2.62
C11S	12	3.1	16.33	2.68
C11S	13	2.8	19.12	3.14
C11S	14	3.1	18.63	2.62
C11S	15	2.8	16.85	4.12
C11S composite mass			**234.60**	**43.69**

Table A2. Clam siphon tissue

Chemical	Unit	Location C06		Location C11N		Location C11S	
		Sample LDW17-C06-MARM-Comp01	Sample LDW17-C06-MAST-Comp01	Sample LDW17-C11N-MARM-Comp01	Sample LDW17-C11N-MAST-Comp01	Sample LDW17-C11S-MARM-Comp01	Sample LDW17-C11S-MAST-Comp01
		Remaining	Siphon	Remaining	Siphon	Remaining	Siphon
		6/26/2017	6/26/2017	6/26/2017	6/26/2017	6/26/2017	6/26/2017
PAHs							
1-Methylnaphthalene	µg/kg ww	0.48 U	0.49 U	0.47 U	0.49 U	0.49 U	0.49 U
2-Methylnaphthalene	µg/kg ww	0.48 U	0.49 U	0.47 U	0.49 U	0.49 U	0.49 U
Acenaphthene	µg/kg ww	1.33	0.49 U	1.04	0.49 U	0.87	0.49 U
Acenaphthylene	µg/kg ww	0.48 U	0.49 U	0.47 U	0.49 U	0.49 U	0.49 U
Anthracene	µg/kg ww	1.34	0.50	1.24	0.97	0.97	0.58
Benzo(a)anthracene	µg/kg ww	6.80	1.84	5.53	5.11	4.62	3.37
Benzo(a)pyrene	µg/kg ww	3.32	2.10	2.88	5.86	2.33	3.64
Benzo(b)fluoranthene	µg/kg ww	4.59	2.97	4.02	7.20	3.03	4.12
Benzo(g,h,i)perylene	µg/kg ww	8.57	2.53	7.90	6.91	5.42	3.87
Benzo(j)fluoranthene	µg/kg ww	2.02	1.23	1.78	3.29	1.41	1.87
Benzo(k)fluoranthene	µg/kg ww	2.43	1.32	2.17	3.66	1.95	2.05
Total benzofluoranthenes - zero DL	µg/kg ww	9.04	5.52	7.97	14.15	6.39	8.04
Chrysene	µg/kg ww	8.63	2.74	7.24	7.35	5.77	4.26
Dibenzo(a,h)anthracene	µg/kg ww	0.54 J	0.52 J	0.47 U	1.72 J	0.49 U	1.07 J
Dibenzofuran	µg/kg ww	0.73	0.49 U	0.60	0.49 U	0.51	0.49 U
Fluoranthene	µg/kg ww	20.3	4.85	16.4	20.0	14.4	8.99
Fluorene	µg/kg ww	1.39	0.49 U	1.12	0.49 U	0.89	0.49 U
Indeno(1,2,3-cd)pyrene	µg/kg ww	1.58	1.91	1.44	5.97	1.11	3.30
Naphthalene	µg/kg ww	0.58 U	0.59 U	0.56 U	0.59 U	0.58 U	0.59 U

Chemical	Unit	Location C06		Location C11N		Location C11S	
		Sample LDW17-C06-MARM-Comp01	Sample LDW17-C06-MAST-Comp01	Sample LDW17-C11N-MARM-Comp01	Sample LDW17-C11N-MAST-Comp01	Sample LDW17-C11S-MARM-Comp01	Sample LDW17-C11S-MAST-Comp01
		Remaining	Siphon	Remaining	Siphon	Remaining	Siphon
		6/26/2017	6/26/2017	6/26/2017	6/26/2017	6/26/2017	6/26/2017
Phenanthrene	µg/kg ww	7.12	1.56	5.29	4.75	4.60	3.30
Pyrene	µg/kg ww	16.9	4.63	15.4	15.2	13.4	7.92
Total HPAHs	µg/kg ww	75.7 J	26.64 J	64.8	82.3 J	53.4	44.46 J
Total LPAHs	µg/kg ww	11.18	2.06	8.69	5.72	7.33	3.88
Total PAHs	µg/kg ww	86.9 J	28.70 J	73.5	88.0 J	60.8	48.34 J
cPAHs 2005 - mammal (half DL)	µg/kg ww	5.0 J	3.0 J	4.3	8.3 J	3.5	5.1 J
Other SVOCs							
2-Chloronaphthalene	µg/kg ww	0.48 U	0.49 U	0.47 U	0.49 U	0.49 U	0.49 U
Benzothiophene	µg/kg ww	0.48 U	0.49 U	0.47 U	0.49 U	0.49 U	0.49 U
Conventionals							
Lipid	% ww	0.86	0.037	1.0	0.068	0.89	0.060
Total solids	% ww	13.4	16.8	14.8	18.5	13.8	17.3

cPAH – carcinogenic polycyclic aromatic hydrocarbon
DL – detection limit
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated concentration
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
SVOC – semivolatile organic compound
U – not detected at given concentration
ww – wet weight



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Map A-1. Total PCB sampling locations in MNR technology assignment areas (ROD Fig. 18)

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Work Plan\Map B-1 6579 Total PCB locations wRemedy.mxd

Harbor I.

Kellogg I.

Slip 1

Slip 2

Slip 3

Slip 4

Slip 6

Upper Turning Basin

MATCH LINE MIDDLE PANEL

LEFT PANEL MATCH LINE

MIDDLE PANEL MATCH LINE

MATCH LINE RIGHT PANEL

- MIT Study - November 2012 (sediment and porewater data)[a]
- MIT Study - Summer/Fall 2014 (porewater data)[a]
- ENR/AC Pilot Study area
- RARE test plot[a]
- Early Action
- LDW Superfund Boundary
- Navigation Channel
- River mile

[a] All locations are approximate pending receipt of data.

0 0.1 0.2 Miles

0 0.2 0.4 Kilometers

Scale is the same for each inset map

Map E-1. Porewater sampling locations in the MIT, ENR/AC Pilot, and RARE studies

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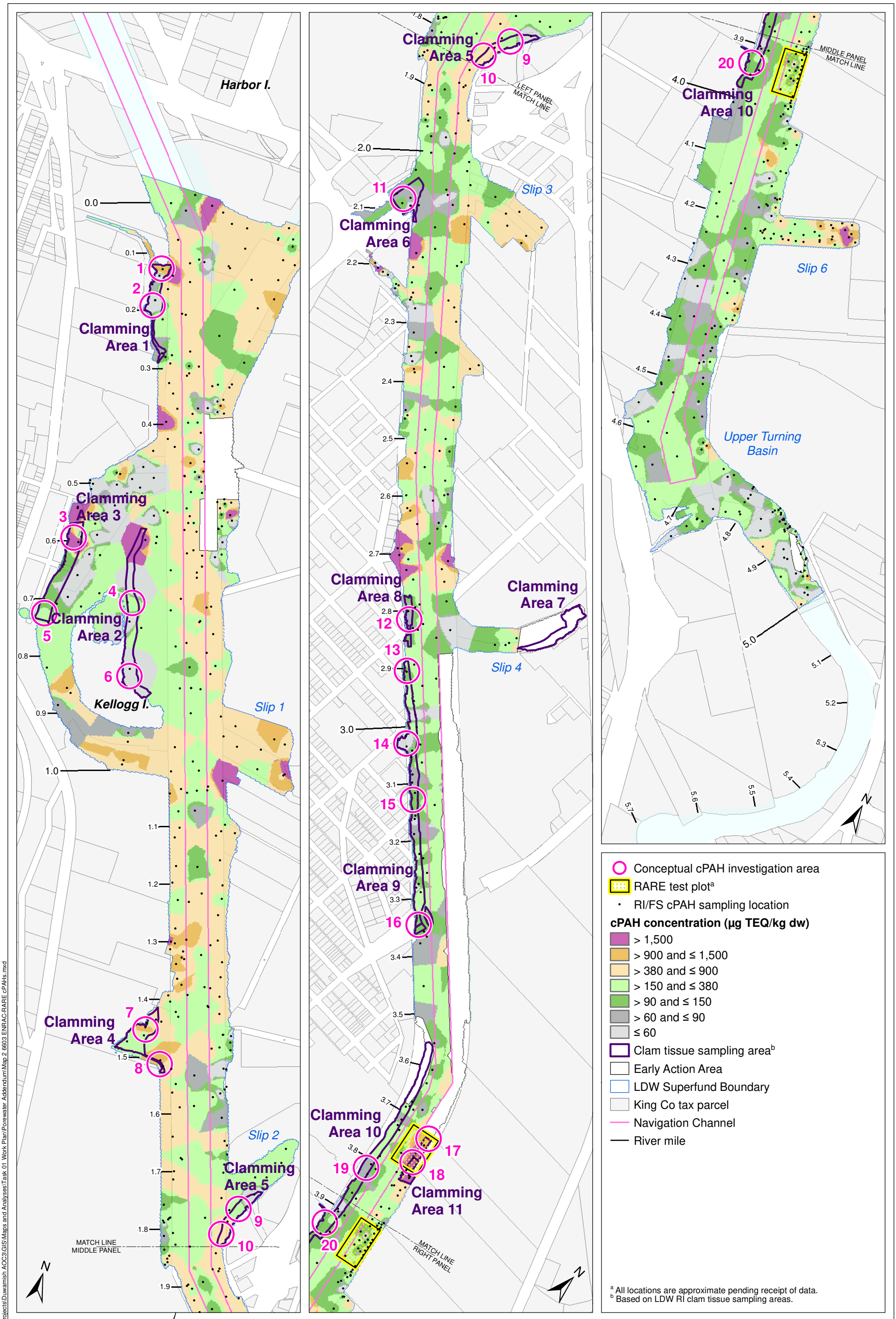
Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Porewater Addendum\Map 1 6519 Porewater sampling plan.mxd



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Map E-2. Conceptual cPAH investigation sampling areas with the RI/FS cPAH interpolation

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Porewater Addendum\Map 2 6603 ENRAC-RARE cPAHs.mxd

Harbor I.
Clamming Area 1
Clamming Area 3
Clamming Area 2
Kellogg I.
Slip 1
Clamming Area 4
Slip 2
MATCH LINE MIDDLE PANEL
Clamming Area 5
LEFT PANEL MATCH LINE
Clamming Area 6
Slip 3
Clamming Area 8
Clamming Area 7
Slip 4
Clamming Area 9
Clamming Area 10
MATCH LINE RIGHT PANEL
Clamming Area 11
MIDDLE PANEL MATCH LINE
Clamming Area 10
Slip 6
Upper Turning Basin

- Conceptual cPAH investigation area
- RARE test plot[a]
- RI/FS cPAH sampling location
- Clam tissue sampling area[b]

Technology assignment (ROD Fig. 18)

- Dredge
- Partial Dredge and Cap
- Cap
- ENR/*in situ*
- Monitored Natural Recovery (Surface Sediment >SCO)
- Monitored natural recovery (Surface Sediment <SCO)
- Early Action Area
- LDW Superfund Boundary
- King Co tax parcel
- Navigation Channel
- River mile

[a] All locations are approximate pending receipt of data.
[b] Based on LDW RI clam tissue sampling areas.

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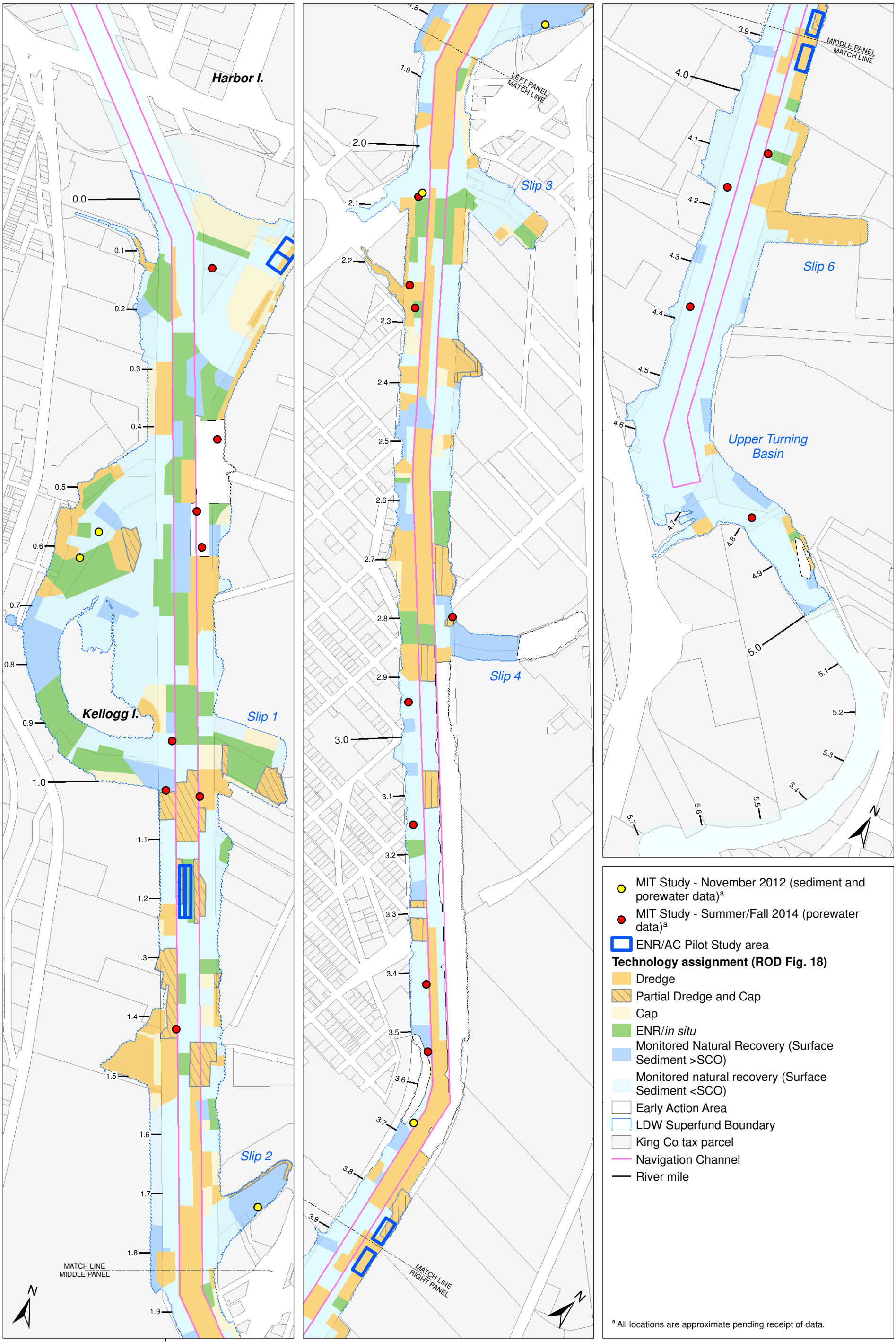
0 0.1 0.2 Miles
0 0.2 0.4 Kilometers
Scale is the same for each inset map

Map E-3. Conceptual cPAH investigation sampling areas with technology assignments (ROD Fig. 18)

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Porewater Addendum\Map 3 6607 ENRAC with Selected Remedy.mxd



[a] All locations are approximate pending receipt of data.

Scale is the same for each inset map

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Map E-4. MIT and ENR/AC Pilot studies with technology assignments (ROD Fig. 18)

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Porewater Addendum\Map 4 6607 MIT-ENRAC with Selected Remedy.mxd

Harbor I.

Kellogg I.

DR005
DR010
DR083
DR092
DUD040
LDW-SS312
WIT288
LDW-SS321
LDW-SS57
DR111
WRC-SS-B3
WIT270
DR258
AN-028
DR290
DR276
Slip 1
Slip 2
Slip 3
Slip 4
Slip 6
Upper Turning Basin
LEFT PANEL MATCH LINE
MIDDLE PANEL MATCH LINE
MATCH LINE MIDDLE PANEL
MATCH LINE RIGHT PANEL

- Conceptual baseline surface sediment location (0-10 cm)
- Additional fixed location for PCB investigation
- Individual location for RAO 3 evaluation (random location in MNR area)
- Individual location for RAO 3 evaluation (re-occupation of SCO exceedance in RI/FS dataset)
- Conceptual sampling area

Total PCBs (µg/kg dw)

- > 1,300
- > 720 and ≤ 1,300
- > 480 and ≤ 720
- > 240 and ≤ 480
- > 100 and ≤ 240
- > 60 and ≤ 100
- > 30 and ≤ 60
- ≤ 30
- Early Action
- Navigation Channel
- River mile

0 0.1 0.2 Miles

0 0.2 0.4 Kilometers

Scale is the same for each inset map

Map E-5. Conceptual PCB investigation sampling locations with the RI/FS total PCB interpolation

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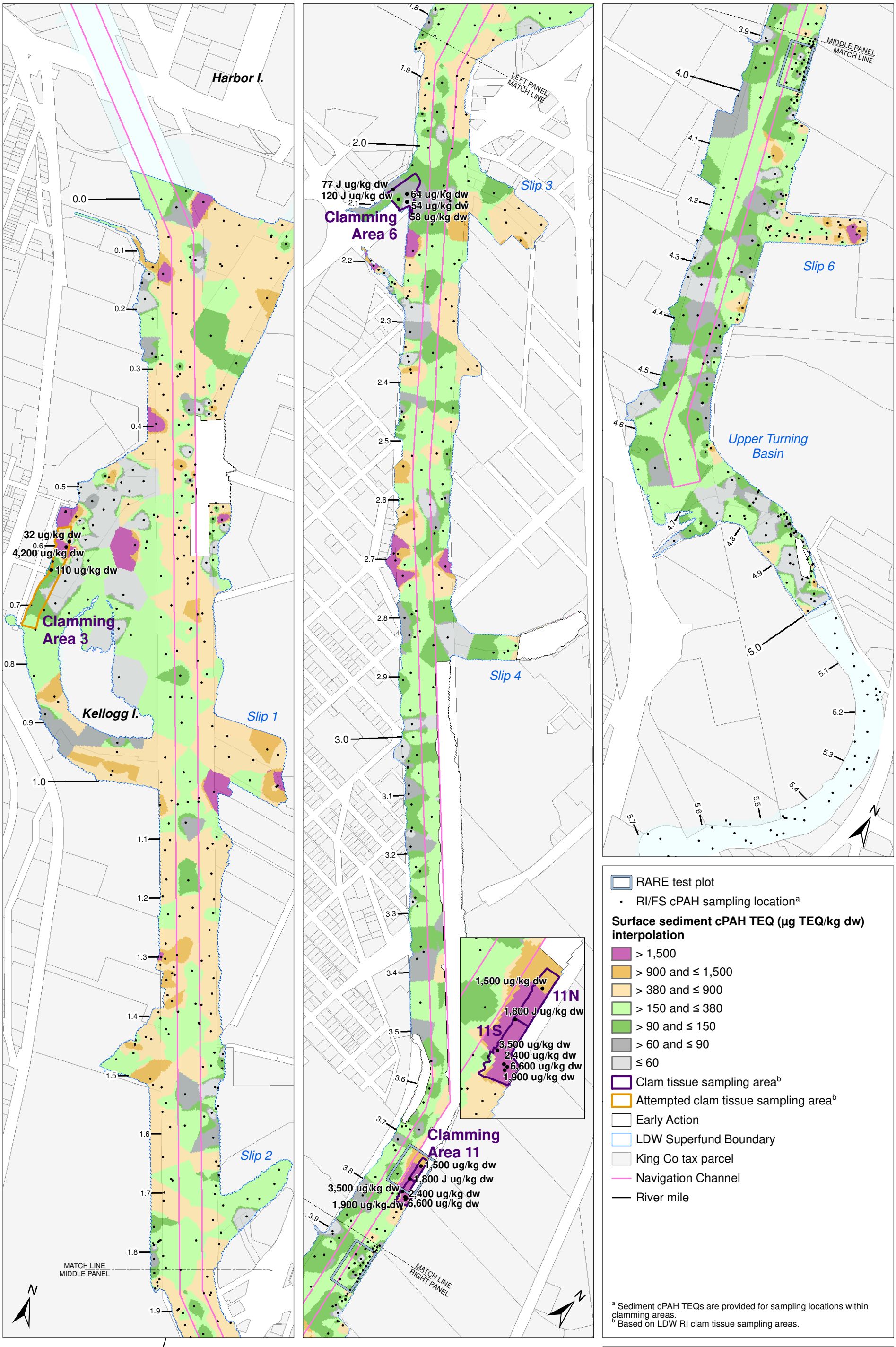
Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Porewater Addendum\Map 5 6649 Conceptual PCB sampling locations.mxd



[a] Sediment cPAH TEQs are provided for sampling locations within clamming areas.
[b] Based on LDW RI clam tissue sampling areas.

Scale is the same for each inset map

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Map F-1. Clam sampling areas to assess cPAH TEQs in clam siphon skin tissue relative to remaining clam tissue

Prepared by craigh, 8/28/2017; W:\Projects\Duwamish AOC3\GIS\Maps and Analyses\Task 01 Work Plan\Clam Siphon Memo\Map 1 6603 ENRAC-RARE cPAHs - lbld.mxd