Lower Duwamish Waterway Group

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

Final Feasibility Study

Lower Duwamish Waterway

Seattle, Washington
Volume I - Main Text, Tables, and Figures

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1 Introduction

This report presents the feasibility study (FS) for the Lower Duwamish Waterway (LDW) Superfund Site in Seattle, Washington (Figure 1-1). This report has been prepared on behalf of the Lower Duwamish Waterway Group (LDWG), consisting of the City of Seattle, King County, the Port of Seattle, and The Boeing Company. LDWG signed an Administrative Order on Consent (AOC)[1] in December 2000 with the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) to conduct a remedial investigation/feasibility study (RI/FS) for the LDW (EPA, Ecology, and LDWG 2000). The LDW was subsequently added to EPA's National Priorities List (also known as Superfund) on September 13, 2001.[2] The LDW was added to Ecology's Hazardous Sites List on February 26, 2002.[3]

In 2003, a Phase 1 RI was prepared based on previously existing information (Windward 2003a). The Phase 1 RI included scoping-phase human health and ecological risk assessments. The Phase 1 RI also facilitated the identification of early action areas (EAAs) and data gaps to be filled during subsequent data collection efforts. In the following years, additional data were collected, as outlined in the Phase 2 Work Plan (Windward 2004) and various project quality assurance project plans (QAPPs) and data reports. Using the additional data that were collected, baseline human health and ecological risk assessments were completed (Windward 2007a, 2007b) and included as part of the RI (Windward 2010).

The Superfund and Model Toxics Control Act (MTCA) cleanup of the LDW includes three components: early cleanup actions, source control, and cleanup of the remainder of the LDW. This FS addresses the third component. Other previously released studies, including engineering evaluation/cost analyses (EE/CA), remedial designs, permitting, and construction/post-construction monitoring have been conducted for the early cleanup actions for smaller areas within and adjacent to the LDW. These documents are relevant to this FS but focus only on discrete areas of the LDW; this FS focuses on five miles of the LDW, extending from just south of Harbor Island (river mile [RM] 0 for the FS) to upstream of the Upper Turning Basin (RM 5.0, Figure 1-1).

The study area evaluated for remedial action in this FS focuses on the sediment and surface water of the LDW (RM 0 to RM 5.0), sometimes referred to as the "site" in this FS for convenience. The terms site, LDW-wide, and site-wide are sometimes used interchangeably in this FS, but generally refer only to the sediment and surface water of

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[1] The AOC for the LDW, including Attachment A, the *Lower Duwamish Waterway Remedial Investigation/Feasibility Study Statement of Work* (LDWG 2000) (EPA Docket No. CERCLA 10-2001-055 and Ecology Docket No. 00TCPNR-1895).

[2] Comprehensive Environmental Response, Compensation, and Liability Information System No. WA0002329803.

[3] FS ID 4297743.

the LDW, not to the upland portions of the LDW Superfund Site. The final LDW Superfund Site boundaries, including upland areas that contributed contamination to the LDW, will be determined by EPA and Ecology in future decision documents.

Investigations and cleanups of facilities, storm drains, and combined sewer overflows (CSOs) within the LDW drainage basin are being conducted to address ongoing sources of contamination to the LDW. Ecology has issued several reports to document the source control strategy (Ecology 2004) for the LDW Superfund Site and the progress to date in addressing ongoing sources of contamination. The RI (Windward 2010) summarized the source control work completed as of July 2010, and more detailed information is available in Ecology's Source Control Status Reports (Ecology 2011b, http://www.ecy.wa.gov/programs/tcp/sites).

The RI/FS work required by the AOC is being conducted under both the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and MTCA (Washington State hazardous waste law similar to CERCLA). Any response actions identified in the FS must comply with both CERCLA and MTCA. The specific documents that define the overall FS process for the LDW site include the following:

- Clarification of Feasibility Study Requirements (LDWG 2003), a clarification letter from LDWG to EPA and Ecology dated December 4, 2003
- The *Feasibility Study Work Plan* for the LDW (RETEC 2007a).

This FS is consistent with the following statutes and regulations:

- CERCLA, as amended (42 United States Code [U.S.C.] 9601 et seq.), and its regulations, the National Oil and Hazardous Substances Pollution Contingency Plan (40 Code of Federal Regulations [CFR] Part 300), commonly referred to as the National Contingency Plan (NCP)
- MTCA, Revised Code of Washington (RCW) Chapter 70.105D and its regulations, Washington Administrative Code (WAC; Chapters 173-340 and 173-204, the latter also called the Washington Sediment Management Standards [SMS]).

In addition, the following guidance documents were considered in developing this FS:

- *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988)
- *Clarification of the Role of Applicable or Relevant and Appropriate Requirements in Establishing Preliminary Remediation Goals under CERCLA* (EPA 1997a)
- *Rules of Thumb for Superfund Remedy Selection* (EPA 1997b)

- *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002b)
- *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005b)
- *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study* (EPA 2000a)
- *Sediment Cleanup Standards User Manual* (Ecology 1991).

1.1 Purpose of the Feasibility Study

The purpose of this FS is to develop, screen, and evaluate LDW-wide remedial alternatives to address the risks posed by contaminants of concern (COCs) within the LDW. This FS is based on the results of the RI (Windward 2010), which included the baseline human health and ecological risk assessments (Windward 2007a, 2007b).

The RI assembled data to identify the nature and extent of contamination in the LDW, evaluated sediment transport processes, and assessed current conditions within the LDW, including risks to people and animals that use the LDW. The FS uses the results of the RI and the baseline risk assessments to identify remedial action objectives (RAOs), develop preliminary remediation goals (PRGs) and cleanup objectives, and develop and evaluate LDW-wide remedial alternatives. The FS lays the groundwork for selecting a cleanup alternative that best manages risks to both human health and the environment.

1.2 The FS Process

The road map through the FS process includes several steps outlined in CERCLA guidance (EPA 1988), as well as additional considerations outlined in *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005b). These general steps and considerations include:

- Summarizing and synthesizing the results of the RI, the baseline human health and ecological risk assessments, and related documents, as well as refining the physical conceptual site model for the LDW.
- Developing RAOs specifying the COCs, exposure pathways, and PRGs that permit an evaluation of a range of remedial alternatives and consider state and local objectives for the LDW.
- Identifying applicable or relevant and appropriate requirements (ARARs) to comply with both state and federal regulations.
- Identifying general response actions for the LDW, including removal, disposal, containment, treatment, enhanced natural recovery, and monitored natural recovery.

- Estimating the sediment volumes or areas of sediments to which the general response actions could be applied.
- Identifying and screening remedial technology types and specific process options best suited to achieve cleanup objectives for the RAOs.
- Assembling the technology types and process options into LDW-wide remedial alternatives.
- Completing a detailed evaluation and comparative analysis of the remedial alternatives consistent with CERCLA and MTCA requirements.
- Evaluating how each alternative would achieve the cleanup objectives for the identified risk drivers as well as how each alternative would address the other COCs.

1.2.1 Integration of CERCLA and MTCA

As stated previously, the RI/FS is being conducted under both CERCLA and MTCA authorities. MTCA regulations also incorporate the Washington SMS regulations by reference.

Table 1-1 compares the major requirements used to select a remedial action under CERCLA with the corresponding requirements under MTCA. Although many CERCLA requirements have MTCA counterparts, there are some important differences. These differences are discussed below.

First, both CERCLA and MTCA have threshold requirements that must be achieved by a remedial action—namely, a remedial action must be protective of human health and the environment and comply with ARARs (generally defined by CERCLA as all federal and more stringent state environmental laws and regulations). In addition to these shared threshold requirements, MTCA requires a specific demonstration that the proposed remedy provides for compliance monitoring. Compliance monitoring is also required for remedial actions under CERCLA when hazardous substances remain on-site at concentrations that do not allow unrestricted use or unrestricted exposure at the site upon completion of the remedial action. Compliance monitoring is required to ensure either that areas are not recontaminated or to evaluate trends over time, such as changes in site-wide spatially-weighted average concentrations (SWACs). The implementing regulations for MTCA require that the nature of the compliance monitoring be discussed specifically.

Second, CERCLA and MTCA share similar balancing criteria for evaluating remedial actions, with very similar frameworks for considering those criteria. For instance, CERCLA prescribes five criteria that are to be balanced in making a remedial decision: long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. CERCLA also requires that EPA "select a remedial action that is protective of human health and the environment, that is cost effective, and that utilizes permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" (CERCLA § 121(b)(1)). Similarly, MTCA requires that Ecology "give preference to permanent solutions to the maximum extent practicable" (RCW 70.105D.030(b)). In determining whether a remedial action uses permanent solutions to the maximum extent practicable under MTCA, a "disproportionate cost analysis" is applied; the analysis takes into account criteria that are essentially equivalent to the five CERCLA balancing criteria. MTCA also requires that restoration be completed within a reasonable time frame and include a long-term monitoring plan. This is similar to the balancing criterion of short-term effectiveness under CERCLA (with the exception concerning monitoring discussed above).

Finally, CERCLA contains two modifying criteria: state and tribal acceptance, and community acceptance. MTCA provides for consideration of local, state, federal, tribal, and community acceptance as part of the disproportionate cost analysis.

Because of the somewhat different CERCLA and MTCA criteria, separate analyses of the remedial alternatives are presented in this FS.

1.2.2 Selecting a Final Remedy

Under CERCLA, the FS presents, evaluates, and compares the remedial alternatives for a site. After review of the FS, the lead agency proposes a final cleanup remedy in a document called the Proposed Plan; this plan is then provided to the public for comment. After public comments on the Proposed Plan are received and evaluated, the lead agency documents the final remedy in a decision document. For CERCLA, this document is called a Record of Decision (ROD). For MTCA, the decision document is the Cleanup Action Plan (CAP), which is functionally equivalent to the CERCLA ROD. The MTCA CAP includes the requirements of the SMS cleanup study report. EPA and Ecology have determined that the cleanup decision document for the LDW will be a CERCLA ROD. The ROD will be issued by EPA with concurrence from Ecology.

The lead agencies for the LDW are EPA and Ecology, and these agencies will ultimately select the final remedy, including the final RAOs and cleanup levels. To this end, the agencies' selection of the final remedy will likely involve weighing the outcomes of evaluations that are conducted under a number of criteria, including:

- The nine CERCLA criteria provided in the NCP for evaluation of remedial alternatives
- The statutory determination requirements in the NCP for selected remedies (40 CFR 300.430(f)(5)(ii))
- Cleanup action requirements under MTCA (WAC 173-340-360) and the SMS (WAC 173-204)

- Risk management principles for sediment sites, as outlined in EPA guidance (EPA 2005b)
- Source control analyses, as described in Ecology's publication *Lower Duwamish Waterway Source Control Strategy* (Ecology 2004).

1.3 Definitions for the Feasibility Study

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

1.3.1 Regulatory Terms

Area background, a term specific to MTCA, represents the concentrations of hazardous substances that are consistently present in the environment in the vicinity of the site as a result of human activities unrelated to releases from the site (WAC 173-340-200). When cleanup levels are less than area background concentrations, MTCA recognizes that area background concentrations can result in recontamination of a site to levels that exceed cleanup levels. In such cases, MTCA allows that portion of the cleanup action to be delayed until off-site sources of hazardous substances are controlled. CERCLA uses the term **anthropogenic (man-made) background** (EPA 1997b), and EPA's sediment remediation guidance (EPA 2005b) states that cleanup levels will normally not be set below natural or anthropogenic background concentrations. However, neither area nor anthropogenic background concentrations have been quantified in this FS. Instead, this FS references the upstream datasets for evaluating incoming, ambient concentrations to the LDW from external sources that may be influenced by urbanization.

Cleanup level under MTCA and CERCLA means the concentration of a hazardous substance in an environmental medium that is determined to be protective of human health and the environment under specified exposure conditions. CERCLA and MTCA provide similar processes for defining and selecting cleanup levels, but some of the terms in the two regulatory programs have slightly different meanings. Cleanup levels are proposed in the FS but are not finalized until the ROD.

Cleanup objective in this FS is used to mean the PRG or as close as practicable to the PRG where the PRG is not predicted to be achievable. This FS uses long-term model-predicted concentrations as estimates of "as close as practicable" to PRGs.

Contaminants of potential concern (COPCs)/Contaminants of concern (COCs) are two related terms used in the baseline risk assessments. The COPCs were initially identified through a conservative risk-based screening process. In this process, contaminant concentrations in sediment, water, and aquatic biota were compared to conservative risk-based screening levels or effects standards. Those contaminants present in any samples from the LDW at concentrations above the screening levels were identified as "contaminants of potential concern," which then underwent further analysis in the baseline risk assessments. The COCs represent a defined subset of the COPCs that were quantitatively evaluated in the baseline risk assessments, considering their distributions in all of the media, and were found to exceed threshold risk levels.

Natural background represents the concentrations of hazardous substances that are consistently present in an environment that has not been influenced by localized human activities (WAC 173-340-200). The MTCA definition includes both substances such as metals that are found naturally in bedrock, soils, and sediments, as well as persistent organic compounds such as polychlorinated biphenyls (PCBs) that can be found in soil and sediments throughout the state as a result of global distribution of these contaminants.

Point of compliance is defined by MTCA as the point or points where cleanup levels shall be achieved (WAC 173-340-200).

Practical quantitation limit (PQL) is defined by MTCA as the "lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods" (WAC 173-340-200). MTCA includes consideration of the PQL in establishing cleanup levels (WAC 173-340-705(6)). Similarly, the NCP (40 CFR 300.430(e)(2)(i)(A)(3)) allows that cleanup levels can be modified based on "factors related to technical limitations such as detection/quantitation limits for contaminants." The term PQL is synonymous with quantitation limit and reporting limit.

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

- ARARs.
- Risk-based threshold concentrations (RBTCs) developed in the risk assessments.
- For final cleanups under MTCA, natural background concentrations are used to develop PRGs if protective RBTCs are below background concentrations.
- Analytical PQLs if protective RBTCs are below concentrations that can be quantified by chemical analysis.

PRGs are presented in the FS as the proposed cleanup levels and standards and will be finalized (as defined above) by EPA and Ecology in the ROD.

Remedial action objectives (RAOs) describe what the proposed remedial action is expected to accomplish (EPA 1999b). They are narrative statements of the medium-specific or area-specific goals for protecting human health and the environment. RAOs are used to help focus development and evaluation of remedial alternatives. RAOs are derived from the baseline risk assessments and are based on the exposure pathways, receptors, and the identified COCs. Narrative RAOs form the basis for establishing PRGs (defined above). RAO is a common CERCLA term. There is no comparable term under MTCA.

Remedial action levels (RALs) are contaminant-specific sediment concentrations that trigger the need for active remediation (e.g., dredging, capping, enhanced natural recovery). This term is used in the FS and has the same meaning as ***remediation level*** under MTCA, which is defined as "a concentration (or other method of identification) of a hazardous substance in soil, water, air, or sediment above which a particular cleanup action component will be required as part of a cleanup action at a site" (WAC 173-340-200). Remediation levels or RALs are not the same as cleanup levels or PRGs. Remediation levels may be used at sites where a combination of cleanup actions is used to achieve cleanup levels at the point of compliance (WAC 73-340-355 (1)). Remediation levels, by definition, exceed cleanup levels. For the purposes of this FS, the ranges of RALs developed for risk drivers consider the magnitude of risk reduction achieved, the rate of natural recovery, and the different types of remedial actions, such as dredging or enhanced natural recovery.

Risk drivers are used in the FS to indicate the subset of COCs identified in the baseline risk assessments that present the principal risks.[4] Risk drivers, as used in this FS, are synonymous with the MTCA term indicator hazardous substances, defined as the subset of hazardous substances present at a site selected for monitoring and analysis or for establishing cleanup requirements (WAC 173-340-200). This FS uses the term risk drivers.

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

Total excess cancer risk is defined by MTCA as "the upper bound on the estimated excess cancer risk associated with exposure to multiple hazardous substances and multiple exposure pathways." In the LDW Human Health Risk Assessment (Windward

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[4] This approach has been used in several RODs, including the Anaconda, MT Superfund site, Operable Unit 4 (EPA 1998c); Wyckoff Co./Eagle Harbor, WA (EPA 2000b); and Puget Sound Naval Shipyard Complex, WA (EPA 2000c).

2007b) and this FS, total excess cancer risk is defined as the sum of all cancer risks for multiple contaminants and pathways for an exposure scenario. For example, total excess cancer risks for the child beach play scenario include the dermal exposure pathway and the incidental ingestion pathway. The term "total risk" also applies to the sum of risks for multiple contaminants under a single exposure scenario. For example, the cumulative sum of cancer risks for PCBs, arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and dioxins/furans for direct contact netfishing exposure is also called total excess cancer risk in this FS.

1.3.2 Sediment Concentrations

Sediment concentrations are expressed and evaluated in the FS in two ways: as individual point concentrations or as SWACs. Risk-based threshold concentrations were developed in the RI and may be expressed as either point concentrations or SWACs (all defined below).

Point concentrations are contaminant concentrations in sediments at a given sampling location, where each value is given equal weight. Point concentrations are typically applied to small exposure areas (e.g., for benthic organisms with small home ranges). Point concentrations usually pertain to smaller-scale management areas for the protection of benthic communities under the SMS.

Risk-based threshold concentrations (RBTCs) are the calculated sediment and tissue concentrations estimated to be protective of a particular receptor for a given exposure pathway and target risk level. RBTCs are based on the baseline risk assessments and were derived in the RI. Sediment RBTCs are used along with other site information to set PRGs (defined above) in the FS.

Spatially-weighted average concentrations (SWACs) are similar to a simple arithmetic average of point concentrations over a defined area, except that each individual concentration value is weighted in proportion to the sediment area it represents. SWACs are widely used in sediment management and are integral to the determination of sediment cleanup levels. The selected area over which a SWAC would be applied may be adjusted for a specific receptor or activity. For example, LDW-wide SWACs may be appropriate for estimating human health risks associated with consumption of resident seafood, but not for direct contact risks from the collection of clams (which may be harvested only in certain areas), or for risks from direct contact with sediments during beach play (which represents a smaller exposure area). In this manner, site-wide or area-wide SWACs are intended to provide meaningful estimates of exposure point concentrations for either human or wildlife receptors.

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

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

1.3.3 Terms for Spatial Areas

Definitions of relevant spatial areas used previously in the LDW RI/FS process are provided below, along with definitions that are used in this FS. These definitions describe areas likely to require remediation.

Early action areas (EAAs) are areas identified for management actions (to be completed prior to starting construction of the selected remedy for the LDW) to reduce unacceptable risks in surface sediments. These areas are under some formal process that commits individual parties to conduct sediment cleanup. In 2003, LDWG proposed seven areas as candidates for early cleanup (Windward 2003b). Of the seven initially proposed, five areas are referred to as the EAAs in this FS (Figure 1-2):

- Duwamish/Diagonal
- Slip 4
- Terminal 117
- Boeing Plant 2/Jorgensen Forge
- Norfolk Area.

Early action cleanups have been completed in all or portions of three EAAs by King County, The Boeing Company, and the City of Seattle, and remedy decisions have been issued by EPA for the other two.[5] Sediment cleanups were conducted in the vicinity of

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[5] The EAA boundaries are represented in this FS based on best available information as of October 2010 as documented in design documents and final cleanup reports used to delineate EAA boundaries. The Duwamish/Diagonal EAA boundary has been revised from the version used in the RI (Windward 2010) by removing the thin-layer placement area from the EAA footprint. The boundaries of the other EAAs used in this FS match those in the RI, but may differ from the final cleanup boundaries presented in the respective removal design documents or subject to the implemented actions. The Slip 4 and Terminal 117 EAA boundaries used in this FS represent those in the EPA-approved project (EE/CAs; Integral 2006 and Windward et al. 2010). The Boeing Plant 2 boundary was defined in 2008 with EPA approval of the Horizontal Boundary Technical Memorandum (Geomatrix and FSI 2008) and the subsequent Final Decision and Response to

the Norfolk combined sewer overflow/storm drain (CSO/SD) at the Norfolk EAA in 1999 and in the vicinity of the Duwamish/Diagonal CSO/SD in 2004/2005 by King County under a 1991 Natural Resource Damage Consent Decree. A much smaller sediment cleanup was conducted at the Norfolk EAA in 2003 by The Boeing Company in the vicinity of the Boeing Developmental Center's south storm drain under Ecology's voluntary cleanup program. In 2012, active cleanup was completed in Slip 4 by the City of Seattle under a formal cleanup Settlement Agreement, also known as an Order, with EPA. The two other EAAs (Boeing Plant 2/Jorgensen Forge and Terminal 117) are in various stages of remedial planning and implementation under Orders with EPA. Together, these five EAAs cover 29 acres, representing some of the highest levels of sediment contamination in the LDW (refer to Section 2 for additional details).

The EAAs are discussed in this FS because they are an integral part of the overall cleanup effort for the site. The EAAs are not included in the cost estimates for remedial alternatives. However, the areal extent and cleanup costs for these EAAs are provided in Section 8 for informational purposes. Remedial alternatives for the EAAs were evaluated in design reports, EE/CA reports, corrective measures studies, or similar documents (e.g., Integral 2006 and 2007; King County 1996, 2000, and 2003; MCS Environmental and Floyd|Snider 2006; RETEC 2006; Windward et al. 2010; Project Performance Corporation 2003).

Areas of potential concern (AOPC) represent the areal extent of sediments that present unacceptable risks and will likely require active or passive remedial technologies to be applied (e.g., dredging, capping, or future monitoring). The AOPC footprints are delineated using sediment PRGs (either on a point basis or by selecting points where remediation would yield a SWAC that achieves a PRG) and other applicable risk information (e.g., current or future exposure pathways). Sediment management method(s) considered within the AOPCs will be compatible with the physical, chemical, biological, and engineering factors present (EPA 1988, Ecology 1991).

Recovery categories have been delineated to represent areas of the LDW with differing potential for natural recovery based on physical characteristics and chemical trends observed in sediment samples. These categories are defined in detail in Section 6.3.

Site, as noted in the beginning of this section, would typically refer to the entire Superfund Site, as defined by EPA or Ecology. The term "site" is frequently used in this FS to refer to just the sediment and surface water portions of the LDW Superfund Site (RM 0.0 to RM 5.0), and generally not to the upland portions.

Comments for Boeing Plant 2 Sediments (EPA 2011d). The Jorgensen Forge boundary was defined in 2008, and EPA has approved the final EE/CA (Anchor QEA 2011). These boundaries differ from those identified in the 2003 Identification of Candidate Sites for Early Action (Windward 2003b). The two remaining areas proposed as candidates for cleanup were not carried forward as EAAs and are included in the area being considered for remediation in this FS.

1.3.4 Terms Related to Time Frames

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

Construction period. The time assumed necessary to construct the remedial alternatives. This period is assumed to begin 5 years following issuance of the ROD. During this 5-year period, the EAAs will be completed (i.e., Alternative 1); priority source control actions, negotiation of orders or consent decrees, initial remedial design/planning, baseline monitoring, and verification monitoring will also be conducted.

MTCA restoration time frame. The time between the start of construction and achievement of the cleanup objectives for the RAOs, either individually or comprehensively. This is discussed in the context of the MTCA evaluation in Section 11 and is the same as the term "time to achieve cleanup objectives" used for CERCLA.

Monitored natural recovery (MNR) period. The time during which the MNR-specific level of monitoring is needed in areas designated for this passive remedial technology. Monitoring conducted during the MNR period will assess whether sufficient progress is being made toward achieving cleanup objectives, or, alternatively, whether contingency actions are warranted to meet the project goals (e.g., the SMS). This FS makes an important distinction between "MNR" and "natural recovery." "Natural recovery" is a term used to describe the condition where natural recovery processes are expected to continue reducing surface sediment concentrations but no contingency actions are anticipated if cleanup objectives are not achieved.

Time to achieve cleanup objectives. The time from the start of remedial construction to when cleanup objectives (see Section 1.3.1) are achieved.

1.4 Document Organization

The remainder of this document is organized as follows:

- Section 2 (Site Setting, RI Summary, and Current Conditions) builds on the key findings of the RI and focuses on the site characteristics that affect the development of AOPCs, selection of representative technologies, and assembly of alternatives. The FS dataset, which includes additional chemistry data not included in the RI baseline dataset and additional physical data needed for engineering considerations, is summarized in this section.
- Section 3 (Risk Assessment Summary) presents the results of the baseline human health and ecological risk assessments (Windward 2007b and 2007a) and the RBTCs for risk drivers.

- Section 4 (Remedial Action Objectives and Preliminary Remediation Goals) presents the recommended RAOs, ARARs, and identifies PRGs for the FS.
- Section 5 (Evaluation of Sediment Movement and Recovery Potential) presents the framework and analysis of sediment movement in the LDW (through the sediment transport model and the bed composition model), describes the methods for predicting changes in sediment chemistry, and reviews the chemical trends for LDW surface sediments.
- Section 6 (Areas of Potential Concern, Remedial Action Levels, and Recovery Potential) presents the AOPC footprints and the array of RALs that may be applied within the AOPCs, and presents the recovery categories that delineate the potential for natural recovery within the LDW.
- Section 7 (Identification and Screening of Remedial Technologies) screens a broad array of remedial approaches and identifies representative technologies that may be applied to the AOPCs.
- Section 8 (Development of Remedial Alternatives) describes LDW-wide remedial alternatives designed to achieve the RAOs, based on the AOPC footprints and representative technologies.
- Section 9 (Detailed Analysis of Individual Remedial Alternatives) screens the remedial alternatives individually using CERCLA guidance. The risk reduction achieved by each remedy is also discussed.
- Section 10 (CERCLA Comparative Analysis) compares the remedial alternatives on the basis of CERCLA evaluation criteria.
- Section 11 (Detailed Evaluation of MTCA Requirements for Cleanup Actions) evaluates the remedial alternatives on the basis of MTCA requirements. This section also presents the disproportionate cost analysis that evaluates the benefits of each remedial alternative in proportion to its cost.
- Section 12 (Conclusions) summarizes the key findings of the FS and presents a general remedial approach for cleaning up the LDW.
- Section 13 (References) provides publication details for the references cited throughout the text.

Tables and figures appear at the end of the section in which they are first discussed. Details that support various analyses in the FS are presented in the appendices.

Table 1-1 Comparison of CERCLA and MTCA Cleanup Requirements

Criteria	CERCLA Requirements (Federal)	MTCA Requirements (State)
CERCLA and MTCA Threshold Criteria	**Overall protection of human health and the environment**	
	40 CFR 300.430(e)(9)(iii)(A) • How alternative provides human health and environmental protection	The first threshold requirement under MTCA is to protect human health and the environment (WAC 173-340-360(2)(a)(i)); also a component of setting cleanup levels (WAC 173-340-700(2)). MTCA's second threshold requirement is compliance with cleanup standards (WAC 173-340-360(2)(a)(ii)).
	Compliance with ARARs	
	40 CFR 400.430(e)(9)(iii)(B) • Substantive requirements from all federal environmental laws and more stringent state environmental and facility siting laws	MTCA's third threshold requirement is compliance with state and federal laws (WAC 173-340-360(2)(a)(ii)-(iii)). For sediment cleanups, MTCA requires compliance with SMS (WAC 173-340-760).[a]
	Compliance monitoring	
	• Compliance monitoring is not a specific component of CERCLA's selection criteria, but generally required under CERCLA's provisions regarding operation and maintenance of the remedy	MTCA's fourth threshold requirement is to provide for compliance monitoring (WAC 173-340-360(2)(a)(iv)) including protection monitoring, performance monitoring, and confirmational monitoring (WAC 173-340-410).
CERCLA Balancing Criteria and MTCA Minimum Requirements	**Long-term effectiveness and permanence**	
	40 CFR 300.430(e)(9)(C) • Magnitude of residual risk • Adequacy and reliability of controls	MTCA requires use of permanent solutions to the maximum extent practicable (WAC 173-340-260(2)(b)(1)). Practicality is determined using a disproportionate cost analysis (WAC 173-340-360(3)(e)). Part of the disproportionate cost analysis is evaluating "effectiveness over the long term," which includes the same criteria for CERCLA to evaluate long-term effectiveness and permanence (WAC 173-340-360(3)(f)(iv)). MTCA also requires a reasonable restoration time frame (WAC 173-340-360(2)(b)(ii)), institutional controls and financial assurances where necessary, control of present and future releases and migration of hazardous substances (WAC 173-340-360(2)(e) & (f)). MTCA does not allow cleanup to rely primarily on dilution and dispersion (WAC 173-340-360(2)(g)).

Table 1-1 Comparison of CERCLA and MTCA Cleanup Requirements (continued)

Criteria	CERCLA Requirements (Federal)	MTCA Requirements (State)
CERCLA Balancing Criteria and MTCA Minimum Requirements (continued)	**Reduction in toxicity, mobility, or volume through treatment**	
	40 CFR 300.430(e)(9)(D) • Treatment process used and materials treated • Amount of hazardous materials destroyed or treated • Degree of expected reductions in toxicity, mobility, and volume • Degree to which treatment is irreversible • Type and quantity of residuals remaining after treatment • Degree to which treatment reduces the risks from principal threats	The corresponding criterion under MTCA is the evaluation of the permanence of an alternative in the disproportionate cost analysis (WAC 173-340-360(3)(f)(i)). MTCA's individual criteria in evaluating permanence correspond to CERCLA's criterion for evaluating the reduction of toxicity, mobility, or volume.
	Short-term effectiveness	
	40 CFR 300.430(e)(9)(E)(1)-(3) • Protection of community during remedial actions • Protection of workers during remedial actions • Environmental impacts • Time until remedial action objectives are achieved	Short-term risks are evaluated as part of the disproportionate cost analysis under MTCA. MTCA's language is a bit broader, but compliance with CERCLA's requirements would satisfy MTCA's as well (WAC 173-340-360(3)(f)(i)).[b]
	Implementability (technical feasibility, administrative feasibility, availability of services and materials)	
	40 CFR 300.430(3)(9)(F)(1)-(3) • Ability to construct and operate the technology • Reliability of the technology • Ease of undertaking additional remedial actions, if necessary • Ability to monitor effectiveness of remedy • Ability to obtain approvals from and coordination with other agencies • Availability of off-site treatment, storage, and disposal services and capacity • Availability of necessary equipment and specialists • Availability of prospective technologies	Technical and administrative implementability is part of the disproportionate cost analysis and includes a very similar assessment of administrative issues and availability of services and materials (WAC 173-340-360(3)(f)(vi)).[c]
	Cost	
	40 CFR 300.430 (e)(9)(G)(1)-(2) • Capital costs, direct and indirect • O&M costs • Net present value of capital and O&M cost	MTCA includes similar cost considerations in the disproportionate cost analysis.[d]

Table 1-1 Comparison of CERCLE and MTCA Cleanup Requirements (continued)

Criteria	CERCLA Requirements (Federal)	MTCA Requirements (State)
CERCLA Modifying Criteria	**Community acceptance**	
	40 CFR 300.430(e)(9)(I) - Completed after the public comment period on the Proposed Plan.	MTCA requires consideration of public concerns solicited throughout the cleanup process pursuant to WAC 173-340-600 and community acceptance (including concerns of individuals, community groups, local governments, tribes, and federal and state agencies) is one of the factors to be weighed in performing a disproportionate cost analysis (WAC 173-340-360(3)(f)(vii)).
	State and tribal acceptance	
	40 CFR 300.430(e)(9)(H) - Completed after the public comment period on the Proposed Plan.	Same as for Community Acceptance

Sources: EPA 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. Interim Final*. EPA/540/G-89/004. October 1988.
Ecology 2001. Model Toxics Control Act. Title 173, Washington Administrative Code, Chapter 173-340. Amended February 12, 2001.

Notes:

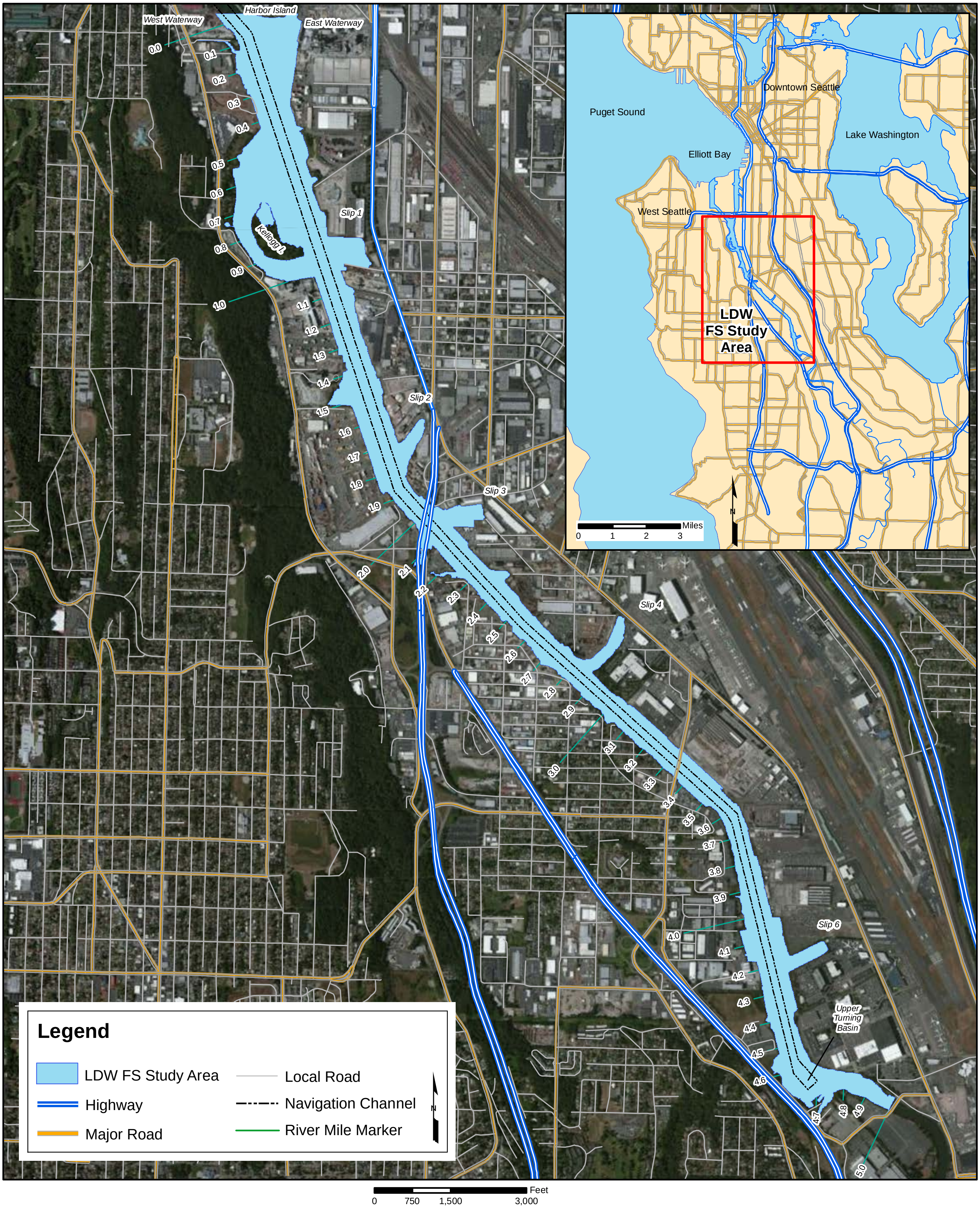
a. SMS requirements are a part of and are consistent with MTCA. SMS *numerical* criteria address risk to the benthic community and apply only to RAO 3 in this FS. SMS *narrative* criteria for protection of human health and biological resources are consistent with MTCA and CERCLA, which define the approach for addressing RAOs 1, 2, 3, and 4 in this FS.

b. The SMS generally requires that cleanup actions meet a "minimum cleanup level" defined as "the maximum allowed chemical concentration and level of biological effects permissible at the cleanup site to be achieved by year ten after completion of the active cleanup action" (WAC 173-204-570(3)). However, where it is not practicable to achieve minimum cleanup levels, Ecology may authorize longer cleanup time frames. (WAC 173-204-580(3)(b)).

c. See also SMS requirements at WAC 173-204-560(4)(g).

d. The final evaluation of cleanup alternatives under the SMS requires consideration of cost, including consideration of present and future direct and indirect capital, operation, and maintenance costs and other foreseeable costs. WAC 173-204-560(4)(h).

ARARs = applicable or relevant and appropriate requirements; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; CFR = Code of Federal Regulations; O&M = Operation and Maintenance; MTCA = Model Toxics Control Act; RAO = remedial action objective; SEPA = State Environmental Policy Act; SMS = Sediment Management Standards; WAC = Washington Administrative Code



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AECOM

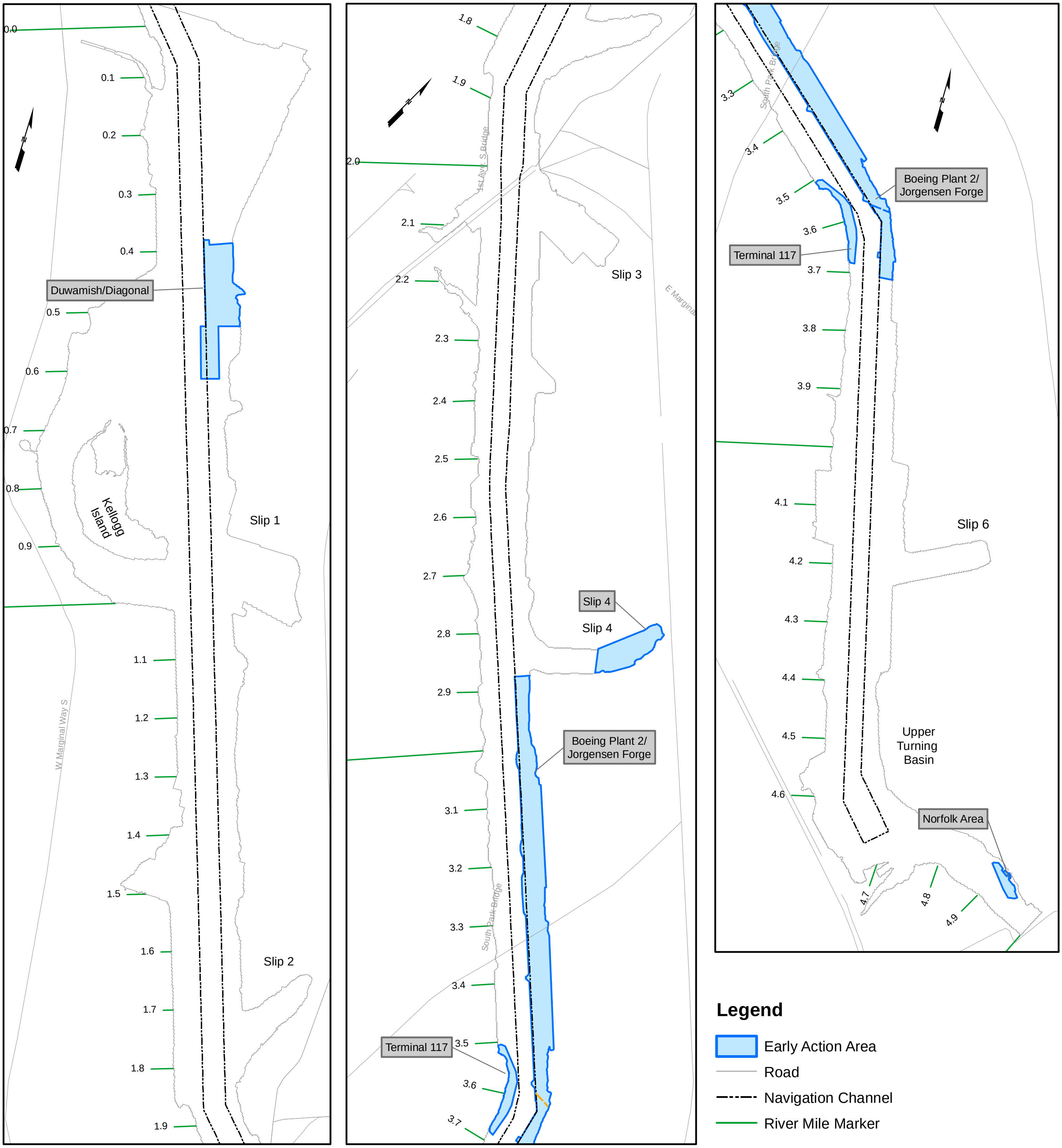
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway
Final Feasibility Study
60150279-14.33

Lower Duwamish Waterway
FS Study Area

DATE: 10/31/12
DWRN:MVI/Sea
Revision: 0

FIGURE 1-1



Notes:

1. The EAAs consist of 29 acres.
2. The Norfolk Area, Duwamish/Diagonal, and Slip 4 EAAs have been the subject of cleanup actions.
3. The Duwamish/Diagonal EAA boundary shown on this map has been revised from the version used in the RI (Windward 2010) by removing the thin-layer placement area from the EAA footprint. The boundaries of the other EAAs used in this FS match those in the RI, but may differ from the final cleanup boundaries presented in the respective remedial design documents or subject to the implemented actions. The Slip 4 and Terminal 117 EAA boundaries used in this FS represent those in the EPA-approved project EE/CAs (Integral 2006 and Windward et al. 2010). In 2012, active cleanup at Slip 4 was completed and cleanup at Terminal 117 was scheduled for completion in 2013/2014. The Boeing Plant 2 boundary was defined in 2008 with EPA approval of the Horizontal Boundary Technical Memorandum (Geomatrix and FSI 2008) and the subsequent Final Decision and Response to Comments for Boeing Plant 2 Sediments (EPA 2011d). The Jorgensen Forge boundary was defined in 2008, and EPA has approved the final EE/CA (Anchor QEA 2011).
4. Dashed line denotes the ownership boundary between Boeing Plant 2 and Jorgensen Forge properties within this EAA.

Feet
0 200 400 800

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AECOM

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway Final Feasibility Study 60150279-14.33			**Early Action Areas**
DATE: 10/31/12	DWRN:MVI/sea	Revision: 1	**FIGURE 1-2**

2 Site Setting, RI Summary, and Current Conditions

This section summarizes the portions of the remedial investigation (RI; Windward 2010) relevant to the feasibility study (FS). It also introduces more recent data made available since finalization of the RI baseline dataset and analyses conducted for engineering purposes.

2.1 Environmental Setting

The Duwamish River originates at the confluence of the Green and Black Rivers near Tukwila, Washington, and flows northwest for approximately 12 miles, splitting at the southern end of Harbor Island to form the East and West Waterways, prior to discharging into Elliott Bay, in Puget Sound, Seattle, Washington.

In the early years of the twentieth century, the last six miles of the Duwamish River were straightened and channelized into a commercial corridor for ship traffic, officially designated as the Lower Duwamish Waterway (LDW) and the East and West Waterways (located near the river mouth). A federally authorized navigation channel runs down the center of the LDW and is 200 ft wide in the downstream reaches and 150 ft wide in the upstream reaches, where it terminates in the Upper Turning Basin at river mile (RM) 4.6 to 4.65. This channel is maintained at depths between -30 ft mean lower low water (MLLW) in the downstream reaches and -15 ft MLLW in the upstream reach.

The LDW Superfund/Model Toxics Control Act (MTCA) study area encompasses 441 acres, is about 5 miles long and approximately 400 feet (ft) wide (with many variations in width where slips and Kellogg Island occur), and consists of the downstream portion of the Duwamish River, excluding the East and West Waterways, which are part of the Harbor Island Superfund site. The LDW study area includes 4.65 miles of the navigation channel and a small portion of the river upstream of the Upper Turning Basin (Figure 1-1).

Outside of the navigation channel, the benches are comprised of sloped subtidal embankments created by the navigation channel deepening, shallow subtidal and intertidal areas (including five slips along the eastern shoreline, and three embayments along the western shoreline), and an island, Kellogg Island, at the downstream end on the western side of the navigation channel. In addition, a comparatively deep area (up to -45 ft MLLW) is present outside the navigation channel between RM 0.0 and 0.4.

The Upper Turning Basin serves as a trap for most of the bed load sediment carried downstream by the Green/Duwamish River. The Upper Turning Basin and portions of the navigation channel just downstream of the Upper Turning Basin are dredged periodically to remove accumulated sediment, reduce sediment transport into the lower reaches of the LDW, and maintain appropriate navigation depths.

The Green/Duwamish River and LDW flow through an industrial and mixed-use residential area in the City of Tukwila, unincorporated King County, and the southern portion of the City of Seattle. The LDW corridor is one of Seattle's primary industrial areas. Two Seattle neighborhoods, South Park and Georgetown, are also adjacent to the LDW to the west and east, respectively. These neighborhoods support a mixture of residential, recreational, commercial, and industrial uses.

The LDW is used for vessel traffic, primarily bulk carriers, tugs, barges, and small container ships, and, to a lesser extent, recreational vessels (refer to Section 2.6.6 for a discussion of vessel traffic). The LDW supports considerable commercial navigation, but is also used for various recreational activities such as boating, kayaking, fishing, and beach play. The LDW, which connects Puget Sound to the Green River, is also an important migratory pathway for salmon.

The LDW is frequently used by Native American tribes as a resource and for cultural purposes. The Muckleshoot Indian Tribe and Suquamish Tribe are both federally recognized tribes and are natural resource trustees for the Duwamish River. The Muckleshoot Indian Tribe currently conducts seasonal commercial, ceremonial, and subsistence netfishing operations in the LDW. The Suquamish Tribe actively manages resources north (downstream) of the Spokane Street Bridge, located just north of the LDW study area.

2.1.1 Site History

The LDW is an estuary that has been extensively modified over the past 100 years by the diversion of two major rivers (the White River and the Cedar River) and by dredging and other modifications.

In 1906, the White River was diverted from the Green River to the Puyallup River to help control flooding.[1] In 1916, the Cedar River was diverted to Lake Washington to provide water for the Lake Washington Ship Canal, a portion of which connects Lake Washington to Lake Union, and resulted in a drop in the elevation of Lake Washington. This caused the Black River, which had been fed by the Cedar River before it flowed into the Duwamish River, to be reduced to a minor stream. The point where this former tributary once joined the Duwamish River is where the Green River becomes the Duwamish River. The Green River is now the primary headwater of the Duwamish River.

These events reduced the flow volume and area of the Duwamish River watershed by about 70%, thus altering the transport of sediment into and within the system. In addition, the Howard Hanson Dam was constructed in 1961 approximately 65 miles

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[1] The White River had been a tributary to the Puyallup River approximately 5,700 years earlier, before a mudflow from Mount Rainier diverted it to the Green River (Booth and Herman 1998).

upstream of the LDW. Construction of the dam effectively decreased peak river flows, which now rarely exceed 12,000 cubic ft per second (cfs). Previously, large flood events (15,000 to 30,000 cfs) occurred. These changes to the river system's hydrology make the dynamics considered in the FS different from those of a natural river of similar size. Sediment dynamics in the LDW are discussed in Section 5.

Between the late 1800s and the mid-1900s, the Duwamish estuary and Elliott Bay underwent massive modifications as the navigation channel and Harbor Island were constructed to support Seattle's early industrial development (Table 2-1). A 1905 U.S. Army Corps of Engineers (USACE) bathymetric survey revealed a meandering river with most of the recorded mudline elevations along the channel being at 0 ft relative to the extreme low water line of 1897. Maximum depths along this channel extended to -10 ft in this datum (Pope 1905). Creation of the East, West, and Lower Duwamish Waterways involved dredging navigation channels, filling marshes and tideflats, and armoring shorelines with levees, bulkheads, slope protection, and other structures. This development resulted in the replacement of about 9.3 miles of meandering river with 5.3 miles of straightened channel by 1916 (Battelle 2001).

Many of the natural curves of the estuary were eliminated when construction of the navigation channel began in 1901 (Figure 2-1). The slips on the east side of the LDW are remnants of those meanders, and the shoreline on the western side of Kellogg Island, a wildlife refuge, reflects the original estuary configuration. Harbor Island, the terminus of the LDW, is a man-made island in an area once occupied by extensive tideflats.

Dredging conducted between 1903 and 1905 created the East and West Waterways, and dredged material from the river was used to create Harbor Island (Weston 1993). As industrial development continued through the 1900s, the East, West, and Lower Duwamish Waterways were deepened and widened to provide vessel access to various industries. Together, the three waterways currently provide over seven miles of inland navigation accessible from Elliott Bay, Puget Sound, and the Pacific Ocean (Battelle 2001).

Kellogg Island is highly altered from its historical size, shape, and function as the result of creating the LDW and the later dredging and diking for dredged material filling that occurred from the late 1940s or early 1950s through the 1970s. These activities greatly altered the island's interior (Canning et al. 1979).

Today, the slips on the east side of the LDW, originally old meander remnants, do not retain their natural character, having armored shorelines that have been filled to steep bank slopes. The shorelines of the slips are dominated by berthing areas and overwater structures. Approximately 3.7 miles of exposed bank are currently present in the LDW, of the approximate 18 miles of combined shoreline and dock face. Very little of this exposed bank is in the location of the original natural meandering riverbank.

2.1.2 Ownership History

Prior to 1920, the LDW was created by King County Commercial Waterway District No. 1 after it had acquired the property necessary for the relocation of the Duwamish River into a commercial waterway. The Waterway District initially created and then maintained navigation depths for a width of 250 feet on either side of the centerline in the LDW. When the Rivers and Harbors Acts of March 1925 and July 1930 authorized the Seattle Harbor Federal Navigation Project and maintenance dredging program, the USACE became responsible for maintaining the navigation channel (USACE 2006).

In 1963, the state legislature authorized port districts to assume all of the assets, liabilities, and functions of the commercial waterway districts. By resolution dated August 13, 1963, the Port of Seattle did so for King County Commercial Waterway District No. 1. Figure 2-2 illustrates the ownership within the LDW.

2.1.3 Hydrogeology, Sediment Stratigraphy, and Surface Water Hydrology

The hydrogeology and sediment properties of the LDW have been influenced both by natural events over geologic time (e.g., earthquakes and lahars, which are mudflows of volcanic material that flow down a river valley) and by anthropogenic events (e.g., channel straightening, dredging, and filling). The Osceola Mudflow and subsequent lahars from Mount Rainier (which occurred approximately 5,700 to 1,100 years ago), cumulatively extended the Duwamish Valley seaward by approximately 30 miles to its current extent (Collins and Sheikh 2005). Lahar events are recorded in the near-surface alluvial deposits of the Duwamish Valley, which extend to depths of roughly 200 ft below ground surface (bgs). These deposits are located within a trough bounded and underlain by either the bedrock unit or dense glacial deposits and non-glacial sedimentary deposits. The geologic history of this valley suggests that the alluvial deposit sequences include estuarine deposits, typically fine sands and silts (often including shell fragments), which progress upward into more complex, interbedded, river-dominated sequences of sand, silt, and gravel. These layers of alluvial deposits delineate the areas of advancing river delta sedimentation that increase in thickness from south to north (Booth and Herman 1998).

On a regional scale, the fill and alluvial deposits can be separated into various generalized units. These units show evidence of the portions of the LDW that used to be meandering river and that were originally upland. They are also used to identify the subsurface depths exhibiting natural properties and those that represent anthropogenic influences.

Based on information derived from upland borings (which can characterize the stratigraphic units of the historical Duwamish River and its floodplain prior to channelization) and LDW sediment cores, these soil and sediment units in the LDW (from younger to older) are:

- **Fill –** The lower Duwamish River was straightened in the early 1900s into a navigation channel, using fill materials derived mostly from local sources. Much of the fill placed in the old river channels during the period of straightening was material dredged to form the straightened channel (USACE 1919), and is similar in hydraulic conductivity to the native younger alluvium. In the vicinity of the LDW, various depths of fill are present, ranging in thickness from 3 to 20 ft. Locally, the shallowest aquifer occurs within the lower portion of this fill material, especially in the northern sections of the LDW where upland areas were created during the last century. The depth of fill varies greatly and generally consists of sand and silty sand in the saturated zone.

- **Younger Alluvium (Qyal) –** Younger alluvium deposits are composed predominantly of sand, silt, gravel, and cobbles deposited by streams and running water (USGS 2005). Younger alluvium has been identified at the bottom of filled Duwamish River channels (USGS 2005). In the central Duwamish Valley, roughly between RM 2.0 and RM 5.2 (with RM 0 being the southern end of Harbor Island and RM 5.2 being just upstream of the study area), younger alluvial deposits are of relatively constant thickness and depth, generally within 5 to 10 ft of present-day mean sea level. These deposits are thicker in the upstream portions of the LDW, with the thickest deposits estimated at a depth of roughly 100 ft bgs. The younger alluvium includes abundant natural organic material, and is often distinguished from the overlying fill by abundant fibrous organic material typical of tidal marsh deposits (USGS 2005). The younger alluvium may also have some gravelly layers.

- **Older Alluvium (Qoal) –** The older alluvium is characterized by estuarine deposits, often including shells at lower depths, and is composed of silts and clays with sandy interbeds (USGS 2005). The older alluvium is commonly identified between 50 and 100 ft bgs in the central Duwamish Valley, increasing in depth toward the mouth of the LDW to a range of 150 to 200 ft bgs. The older alluvium has been best characterized between RM 3.0 and 3.5 (Reach 2) in the central valley, where the older alluvium becomes finer-grained with increasing depth. In this area, the upper two-thirds of the older alluvium typically consist of sand and silty sand, and the lower third consists of sandy silt (Booth and Herman 1998). The older alluvium also becomes significantly finer at the downstream end, with the sand almost completely absent near the mouth of the LDW. Near this downstream location, the older alluvium is composed almost entirely of silt and clay, representing the farthest extent of the delta deposits into the marine waters and displaying the finest-grained material of the Duwamish Valley alluvial sequence.

Based on field observations from the 2006 RI cores and review of core logs from historical reports identified for the RI (Windward 2010) or downloaded from the GeoNW database (ESS 2007), the LDW younger alluvium sediments were grouped into three stratigraphic units. These units were delineated primarily based on unity of density, color, sediment type, texture, gross appearance, and distinct horizon changes:

- Recent material dominated mostly by unconsolidated organic silt
- Interbedded silt and sand with woody debris and shell fragments often present
- Dense non-silty brown sand with silty layers (prechannelization).

Other information (including the presence of debris, depth of unit relative to the units in surrounding cores, and available information on historical dredging events) was also considered. The delineation of these stratigraphic units is important for evaluating remedial alternatives in the FS. Figure 2-3 provides a longitudinal cross section through the LDW navigation channel, and shows the approximate difference in elevations and thicknesses of these units between upstream and downstream areas of the LDW.

The hydrology of the LDW is also affected by the salt wedge, where freshwater from the upstream Green/Duwamish River overlies denser saltwater from Elliott Bay. Water circulation within the LDW, a well-stratified estuary, is driven by tidal actions and river flow; the relative influence of each is highly dependent on seasonal river discharge volumes. Freshwater flowing from the Green/Duwamish River system enters the headwaters of the LDW, and saltwater from Puget Sound enters the lower reaches of the LDW from its mouth. Typical of tidally influenced estuaries, the LDW has a relatively sharp interface between the freshwater outflow at the surface and saltwater inflow at depth. As the freshwater flows over the deeper saltwater wedge, only limited mixing occurs between these freshwater and saltwater lenses, resulting in a lens of freshwater overlying the salt wedge over a significant portion of the LDW a significant portion of the time. The salinity of the surface water varies with river flow and tidal conditions; during times of high river flow, the salinity in the surface water is low, whereas during low-flow conditions, the surface water salinity is higher. Santos and Stoner (1972) characterized the circulation patterns within the tidally influenced water (or salt wedge) area of the LDW, which typically extends from Harbor Island to near the head of the navigation channel. When freshwater inflow is greater than 1,000 cfs, the saltwater wedge does not extend upstream beyond the East Marginal Way South Bridge (RM 6.3; upstream of the study area), regardless of the tide height. During high-tide stages and periods of low freshwater inflow, the saltwater wedge has been documented as extending as far upstream as the Foster Bridge (RM 8.7) (Santos and Stoner 1972). At the river's mouth at the northern end of Harbor Island, a salinity of 25 parts per thousand (ppt) is typical for the entire water column; salinity decreases toward the upriver portion of the estuary. The thickness of the freshwater layer increases throughout the LDW as the river flow rate increases.

Dye studies indicate that downward vertical mixing over the length of the saltwater wedge is almost non-existent (Schock et al. 1998). Santos and Stoner (1972) described how the upstream location or "toe" of the saltwater wedge, typically located between Slip 4 and the head of the navigation channel, is determined by both tidal elevation and freshwater inflow. Fluctuations in tidal elevation also influence flow in the upper freshwater layer, which varies over the tidal cycle.

The U.S. Geological Survey (USGS) measured the average net upstream transport of saltwater below the Spokane Street Bridge and reported it to be approximately 190 cfs (Clemens 2007). This average net upstream flow is about 12% of the average downstream flow measured at the Tukwila gauging station.[2] During seasonal low-flow conditions, saltwater inputs from the West Waterway were more than one-third of the total discharge from the LDW (Harper-Owes 1983).

2.1.4 Seismic Conditions

The Puget Sound region is vulnerable to earthquakes originating primarily from three sources: 1) the subducting Juan de Fuca plate (intraplate), 2) between the colliding Juan de Fuca and North American plates (subduction zone), and 3) faults within the overriding North American plate (shallow crustal) (EERI and WMDEMD 2005). Earthquakes have the potential, depending on epicenter, magnitude, and type of ground motion, to change the vertical and lateral distribution of contaminated sediments in the LDW and soils in the Duwamish drainage basin. This potential is considered during the development and evaluation of remedial alternatives in this FS and will be refined during the remedial design phase.

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[2] The USGS Green River gauging station #12113350 is located at RM 12.4.

The following are examples of regional earthquakes by source, estimated probability of occurrence in any given 50-year interval, type and date of events that have historically occurred, and their magnitude (Moment Magnitude Scale [M]),[3] (EERI and WMDEMD 2005):

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

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

The Seattle Fault is believed to be capable of generating another major earthquake of M7 or greater (Pratt et al. 1997, Johnson et al. 1996, Brocher et al. 2000). EERI and WMDEMD (2005) developed a hypothetical Seattle Fault earthquake scenario for guiding regional preparation and responses to such a foreseeable event. The earthquake in this scenario was of magnitude M6.7, which has an estimated 5% probability of occurrence in any given 50-year period (once in approximately 1,000 years). This scenario is approximately equal in magnitude to the 1,100-year old Seattle Fault event. This scenario is based upon a shallow epicenter with a surface fault rupture (as opposed

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

to the deeper epicenters with other recent events such as Nisqually [2001], Seattle-Tacoma [1965], and Olympia [1949]). The Seattle Fault scenario would have major consequences for liquefaction-induced ground movements that could damage in-water and upland infrastructure in the Duwamish River Valley and lower Green River Valley. Damage to chemical and fuel storage tanks could result in releases. Under the scenario, ground deformation could be up to 3 ft, which would impact seawalls and release upland soils into the LDW. An earthquake of this magnitude would also likely cause widespread disruption of essential services.

Tsunamis could also affect the vertical and horizontal distribution of sediment contamination remaining in the LDW following cleanup and could contribute additional contaminants derived from other sources. Titov et al. (2003) modeled a M7.3 earthquake at the Seattle Fault and the resulting tsunami bore was modeled southward to approximately RM 1.5 on the LDW. The modeled tsunami would inundate Harbor Island, the South of Downtown District, and uplands along that portion of the LDW. The model also predicts some locally high velocities over the bench areas as the bore moves through the lower reach of the LDW.

Palmer et al. (2004) classify the soils in the bottom lands of the Duwamish and Lower Green River valleys as being susceptible to liquefaction, which would tend to magnify earthquake-induced motion. Surficial deposits of clean, dark, fine to medium sand from prehistoric liquefaction-induced ground failure dikes have been observed along the LDW at and near Kellogg Island. These deposits appear to be extrusions of deeper sediments into tidal-marsh deposits that were deposited after the Seattle Fault uplift approximately 1,100 years ago. The largest of the dikes is as much as 18 centimeters (cm) wide and 6 meters long. Kayen et al. (2007) concluded:

> *"Analysis of the stability of the Holocene deltaic deposits using field penetration test data indicates that extensive soil liquefaction and ground failure of native deltaic deposits are likely during moderate to large earthquake events."*

Section 8.1.3.2 includes information about how seismicity has been integrated into other feasibility studies and remedial designs for other projects in the LDW and the adjacent Elliott Bay. In addition, Section 8 discusses post-event responses of monitoring, detection, and repair following an earthquake as integral features of remedial alternatives.

2.1.5 Ecological Habitats and Biological Communities

Ecological habitats of the LDW have been modified extensively since the late 1800s as the result of hydraulic changes, channel dredging, filling of surrounding floodplains, and construction of overwater and bank stabilization structures. The only evidence of the river's original, winding course is present in the remnants of some of the natural meanders along the LDW (several of which are now used as slips) and the area around

Kellogg Island. Remnants of habitat also remain in the LDW, and portions of intertidal habitat are the focus of recent restoration efforts.

Several habitat restoration projects (some including the construction of new public parks) have already been completed. Habitat restoration areas to date in the LDW and immediately upstream of the study area include (Figure 2-4; Windward 2010):

- Port of Seattle/Coastal America at T-105 where a side channel slough was created at a former industrial property at RM 0.1W
- T-107 Public Access Site/Herring's House Park, at RM 0.3W to RM 0.7W near Kellogg Island, where intertidal habitat has been restored at the site of a former lumberyard and habitat restoration has been conducted at the mouth of Puget Creek
- Diagonal Avenue S/T-108 restoration area at RM 0.6E
- General Services Administration marsh restoration area at RM 0.8E
- First Avenue Bridge boat ramp (public access) at RM 2.0E
- Derelict barge removal at RM 2.0W and the construction by the Washington State Department of Transportation of a fish and wildlife habitat restoration channel that connects to an emergent vegetation area at the south landfall of the First Avenue Bridge
- Gateway North/8th Avenue South street end restoration area at RM 2.7E
- South Portland street end park at RM 2.8W
- Hamm Creek restoration area at RM 4.3W, where 1 acre of emergent salt marsh, 2 acres of freshwater wetlands, and nearly 2,000 ft of the Hamm Creek stream bed have been restored
- Muckleshoot Tribe restoration area at Kenco Marine near the Upper Turning Basin at RM 4.6W
- Upper Turning Basin at RM 4.7W, where four restoration projects, including several derelict vessel removals, a Coastal America project, and expansion of intertidal marsh for project-specific mitigations have led to a total of 5 acres of restored intertidal habitat
- South 112th Street mitigation site at RM 5.7E
- King County's Cecil B. Moses Park at RM 5.7W.

2.1.5.1 Habitat Types

The dominant natural habitat types in the LDW are intertidal mudflats, tidal marshes, and subtidal areas. About 98% of the approximately 1,270 acres of tidal marsh and 1,450 acres of mudflats and shallows, as well as all of approximately 1,230 acres of tidal wetland historically present in the historical Duwamish estuary, have either been filled or dredged. Areas of remnant tidal marshes account for only 5 acres of the LDW, while mudflats account for only 54 acres (Leon 1980).

Intertidal habitats are dispersed in relatively small patches downstream of RM 3.0, with the exception of the area around Kellogg Island, which represents the largest contiguous area of intertidal habitat remaining in the LDW. In these intertidal habitat areas, birds and mammals can be exposed to contaminants either through direct contact with sediment or through consumption of fish or shellfish. However, these areas also provide wildlife habitat in an otherwise industrial waterway.

Kellogg Island is currently designated as a wildlife refuge. Habitat associated with the island encompasses high and low marshes, intertidal mudflats, and filled uplands. A mixture of introduced and native plant and tree species has colonized this 17.3-acre island.

2.1.5.2 Biological Communities

Based on research conducted for the RI, the LDW is home to diverse communities of fish, birds, mammals, and invertebrate species. Typical of estuarine environments, the benthic invertebrate community is dominated by annelid worms, mollusks, and crustaceans. Crustaceans are the most diverse of these three groups in the LDW, including more than 250 taxa. The most abundant large epibenthic invertebrates include slender crabs, crangon shrimp, and coonstripe shrimp. Dungeness crabs are also common, although their distribution is generally limited to the portions of the LDW with higher salinity. Mollusks include various bivalves and snails. Although the vast majority of benthic invertebrate species in the LDW are typical inhabitants of estuarine environments, a few organisms more typical of freshwater environments were found. For example, during the sampling events conducted for the RI, one chironomid larva was collected in intertidal habitat at RM 0.6, two chironomid larvae were collected in intertidal habitat at RM 1.4, and one chironomid larva was collected in the subtidal habitat at RM 1.6 (Windward 2010).

The LDW is inhabited by numerous anadromous and resident fish species. During sampling events conducted for the RI, 53 resident and non-resident fish species were captured in the LDW. Up to 33 resident and non-resident species of fish had been recorded in the LDW in prior sampling events (Windward 2010). As summarized in the baseline ecological risk assessment (ERA; Windward 2007a), shiner surfperch, snake prickleback, Pacific sandlance, Pacific staghorn sculpin, longfin smelt, English sole, juvenile Pacific tomcod, pile perch, rock sole, surf smelt, three-spine stickleback, Pacific herring, and starry flounder were identified as abundant at the time of the sampling events, as were chinook, chum, and coho salmon. Fish abundance in the LDW is greatest in late summer to early fall and is generally lowest in winter.

The Green and Duwamish rivers support eight species of salmonids: coho, chinook, chum, sockeye, and pink salmon, plus cutthroat trout, both winter- and summer-run steelhead, and bull trout. Coho, chinook, and steelhead runs consist of a combination of hatchery-bred and natural stocks, defined as naturally spawning fish that are descended from both wild and hatchery fish (Pentec 2003). Pink and sockeye salmon and bull trout stocks breed in the wild and are of unknown origin (Kerwin and Nelson 2000). Juvenile chinook and chum salmon are highly dependent on estuarine habitats.

Of the salmonid species, chinook salmon have been studied the most extensively in the Green/Duwamish system. Puget Sound chinook salmon were listed as threatened under the federal Endangered Species Act (ESA) on March 24, 1999. The decline of chinook salmon has been attributed primarily to habitat degradation and fragmentation, blockage of migratory corridors, impact from hatchery fish, and commercial and local harvesting practices (Myers et al. 1998).

Other species listed as threatened under the ESA include the coastal Puget Sound bull trout, the Puget Sound steelhead, and the bald eagle, the latter of which is currently under review for delisting (Myers et al. 1998).

Salmonid residence time in the LDW is species-specific. Juvenile chinook and chum salmon have been shown to be present from several days to two months within the LDW, whereas coho salmon pass through the LDW in a few days. Sockeye salmon are rare in the LDW. Salmon found in the LDW spawn mainly in the middle reaches of the Green River and its tributaries. The juvenile outmigration of all five species generally commences during the high-flow months of March to June. Outmigration usually lasts through mid-July to early August (Nelson et al. 2004, Warner and Fritz 1995). During these months, salmonids use the estuary to feed and begin their physiological adaptation to higher salinity waters. As a result, the regulatory agencies have established “fish windows,” which generally restrict in-water marine work to the period from October through February.

The aquatic and semi-aquatic habitats of the LDW support a diversity of wildlife species. Formal studies, field observations, and anecdotal reports indicate that up to 87 species of birds and 6 species of mammals use the LDW at least part of the year (Windward 2010).

2.1.6 Historical and Current Land Uses

Prior to the 1850s, the Duwamish River area was occupied by Native American tribal communities that used the area for fishing, hunting, gathering, and some limited farming. Settlers of European origin began to inhabit the area around the 1850s, clearing the Duwamish shorelines and draining wetlands to accommodate logging and agriculture.

Prior to the 20th century, flooding was a common occurrence in the Green/Duwamish river valley. In the early 1900s, continued issues with flooding led to the installation of levees and dams and subsequent channelization of the river (Table 2-1). The Howard Hanson Dam was constructed in 1961 for flood control and low flow augmentation to preserve fish life when river flows were naturally low (Sato 1997).

After channelization of the LDW in the early 1900s, most of the upland areas adjacent to the LDW have been and are still used for industrial purposes that include cargo handling and storage, marine construction, boat manufacturing, marinas, concrete manufacturing, paper and metals fabrication, food processing, and airplane parts manufacturing (Wilma 2001). The upland areas along the upstream portions of the LDW and along the Green/Duwamish River were used for farming. The LDW continues to be used by the Muckleshoot Tribe as part of their Usual and Accustomed Fishing area, and the Suquamish Tribe fishes the area north of the Spokane Street Bridge, immediately north of the LDW.

Industrial development increased as the mudflats were filled with soil from the regrading of Seattle's former hills. In 1928, Seattle's first municipal airport, Boeing Field, was opened. Seven years later, Boeing opened its Plant 2 on the west side of Boeing Field (Wilma 2001).

Although the area surrounding the LDW is largely regarded as an industrial corridor, the Duwamish estuary subwatershed (extending from RM 11.0 to Elliott Bay) of the Green/Duwamish watershed has more residential land use (36%) than industrial and commercial land use combined (29% combined; 18% and 11%, respectively). Eighteen percent of the subwatershed is used for right-of-way areas (including roads and highways); while 17% is open/undeveloped land and parks (Schmoyer, personal communication, 2011a).

The combined (storm and sanitary) sewer service area and separated storm drainage basin (i.e., the upland areas over which source control investigations/activities are occurring) are 19,800 acres and 8,936 acres, respectively. However, the combined and separated areas overlap in many places; the total area discharging to the LDW is 20,400 acres. Within the 19,800-acre combined sewer service area, land uses are: 36% residential, 15% industrial, 10% commercial, 26% right-of-way, and 13% open space. Within the 8,936-acre separated storm drainage basin, land uses are: 23% residential, 29% industrial, 8% commercial, 26% right-of-way, and 15% open space (Schmoyer, personal communication, 2011a).

Two mixed residential/commercial neighborhoods, South Park and Georgetown, are located adjacent to the LDW. The South Park neighborhood, within and adjacent to the southern edge of the Seattle city limit, borders the west bank of the LDW and includes approximately 984 ft of residential shoreline. The Georgetown neighborhood, located east of the LDW and E Marginal Way S, is separated from the LDW by several commercial facilities, although access to the LDW on foot from this neighborhood is possible. The U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) believe there to be potential environmental justice concerns in accordance with Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, for those affected by the LDW site and cleanup. In response, EPA is developing an Environmental Justice Analysis for the LDW Superfund Cleanup, to be published as an appendix to the Proposed Plan.

Four marinas are located in the LDW, and several other access points allow the public to enter the LDW for recreational purposes. In a human access survey conducted along the LDW shoreline as part of the Human Health Risk Assessment (HHRA; Windward 2007b), owners/operators of 93 commercial/industrial, residential, and public properties were surveyed to determine their potential for public access and use. The survey identified 17 locations (in addition to the 4 marinas) used by the public to launch or haul out hand-powered boats or motorboats. In addition, 8 sites along the LDW have been used for swimming, and 10 have been used for picnicking (Figure 2-4). In addition, two public parks (Terminal 107/Herring's House and Duwamish Waterway Park) exist along the LDW shoreline (Figure 2-4). Although recreational use may increase at some point in the future, this area is anticipated to remain primarily commercial, industrial, and residential in use.

2.2 FS Datasets

Between 1990 and 2004, approximately 1,200 surface sediment samples, 340 subsurface sediment cores, and 90 fish and shellfish tissue samples were collected from the LDW by parties other than the Lower Duwamish Waterway Group (LDWG), the entity responsible for performing the RI/FS. These samples and cores were analyzed for metals and organic compounds and the data became part of the RI baseline dataset. Additional data were collected from 2004 to 2006 for the RI/FS to characterize contamination by hazardous substances and physical properties of the LDW. These data included approximately 900 samples of the following media: fish, clam, crab, and benthic invertebrate tissue; seep water (water seeping from banks along the river); surface sediment (the top 10 cm); subsurface sediment (below the top 10 cm); and porewater (water in spaces between sediment particles). Collectively, all of these data represent the baseline dataset used in the RI to characterize the nature and extent of contamination. The RI included data that were available as of October 2006.

Additional data have been collected since the finalization of the RI baseline dataset (i.e., since October 2006). The baseline dataset used in this FS (called the "FS baseline dataset") includes those data newer than October 2006 as well as older data that were not previously included in the RI baseline dataset (Table 2-2). The FS baseline dataset does not include data collected after April 2010. Windward prepared a technical memorandum, *Summary of Chemistry Datasets to be Used in the RI/FS – Addendum 3*, which discusses the data quality for each of these events (Windward 2012, review in progress). Additionally, Appendix N presents the new data included in the FS baseline dataset.

As shown in Table 2-2, data for 174 surface sediment locations and for 509 subsurface sediment samples were added to the RI baseline dataset to create the FS baseline dataset. The percentage of new surface sediment locations in the FS baseline dataset relative to those in the RI baseline dataset varies by analyte; for total polychlorinated biphenyls (PCBs) 7% (101 of 1,392) of the locations in the FS baseline dataset were not in the RI baseline dataset. The RI describes the methods for developing the FS baseline dataset, and Appendix N presents data tables (updated from those in the RI Appendix E).

Additionally, several other datasets, such as those for tissue and water and those for samples collected outside of the LDW, were used in the FS. These other datasets are discussed in Section 2.2.3.

2.2.1 FS Baseline Surface Sediment Data

The sample count for each of the hazardous substances that are human health risk drivers (as described in Section 3) is provided in Table 2-3. This dataset follows the same rules used to establish the RI baseline dataset (Section 4.1.2.1; Windward 2010). Within the early action areas (EAAs) where sediment removal actions have been conducted since the LDW RI/FS Administrative Order on Consent (AOC), (i.e., Duwamish/Diagonal and Boeing Developmental Center south storm drain), the preremedy data are used to characterize baseline conditions.[4] However, because the sediment removal action in the vicinity of the Norfolk combined sewer overflow/storm drain (CSO/SD) was conducted in 1999 prior to the LDW AOC, post-remedy monitoring data from the Norfolk CSO/SD cap are used to represent baseline conditions.

The FS baseline surface sediment dataset includes the baseline dataset used in the RI and the following additional data, which are summarized in Table 2-2. Most of these

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[4] For these areas that have post-remedy monitoring stations with repeated sampling over time, time trend data are used to evaluate the success of remedial technologies (Section 7); for the Duwamish/ Diagonal EAA, the most recent ENR and perimeter data were used in the assembly of remedial alternatives (Section 8).

events were conducted to characterize specific locations; however, two site-wide events were also conducted, as described below and shown in Figures 2-5 and 2-6a through 2-6i:

- Data were collected around the perimeter of and upstream of the Boeing Plant 2/Jorgensen Forge EAA to characterize the boundary of this EAA.
- Surface sediment post-remedy monitoring data were collected around the perimeter of the Duwamish/Diagonal EAA (2005 to 2009) as part of King County's annual monitoring of the cleanup action taken in this area.
- Surface and subsurface sediment data were collected around the perimeter of the Slip 4 EAA for the design report.
- Surface sediment data were collected around the perimeter of the Terminal 117 EAA and analyzed only for total PCBs and dioxins/furans to characterize the boundary of this EAA.
- Data were collected by individual parties at the 8801 E. Marginal (RM 3.9 to 4.0E) and Industrial Container Services (RM 2.2E) facilities. These two facilities are currently under MTCA cleanup orders (Ecology Agreed Order Nos. 6060 and DE 6720, respectively).
- Data were collected by the Port of Seattle in the intertidal area of Terminal 115 (RM 1.8W) prior to 2009 dredging to characterize the intertidal slope shoreward of the dredging prism.
- Data were collected by Ecology to characterize surface sediment upstream of the LDW. Five of these sample locations are at RMs 4.9 and 5.0. The other locations are upstream of the study area, and are thus not a part of the FS baseline dataset. All locations sampled for this event are shown in Figure 2-7. Summary statistics for these data are presented in Table 2-4 and are discussed in Appendix C. A table of all human health risk-driver data from this event is included in Appendix C, Part 3.
- Data from a sediment profile imaging (SPI) study conducted by Ecology were used to examine the feasibility of correlating metrics from sediment profile images with chemical, toxicity, and benthic community data (Gries 2007). This study generated surface sediment chemistry and toxicity data for 30 stations in the LDW from the mouth to Slip 4.
- Historical dioxin/furan data from four EPA 1998 site investigation (SI) surface sediment stations had been removed from the RI baseline dataset in accordance with the RI data trumping rules, which excluded all data for any old location within 10 ft of a newer location. The trumping exercise has

been refined for the FS in that each trumped location was reviewed on an individual contaminant basis. Only the contaminant data for which newer data are available were replaced. Therefore, an older location remains in the dataset when its co-located newer sample was not analyzed for the same suite of analytes as the older location (only the data for the contaminants that were not analyzed in the newer sample are retained from the older sample). Although the data for the trumped contaminants were removed from the FS baseline dataset, they were still used in the FS to evaluate time trends (see Appendix F).

- Data were collected by LDWG in 2009 and 2010. This sampling and analysis effort was conducted to increase the dioxin/furan dataset, which had contained 54 samples in the RI baseline dataset. A second objective of the 2009/2010 LDWG sampling event was to further characterize the beach play areas identified in the HHRA. This event included 41 discrete sediment samples analyzed for dioxins/furans, eight of which were also analyzed for PCBs, arsenic, and carcinogenic polycyclic aromatic hydrocarbons (cPAHs). One grab sample was also analyzed for the full suite of Washington State Sediment Management Standards (SMS) contaminants. Additionally, six composite sediment samples were collected from beaches. However the composite samples were not used in the FS baseline dataset for mapping baseline conditions because only individual grab samples are contained in this dataset. Although not in the FS baseline dataset, the composite samples were used to calculate baseline direct contact risks in beach areas (Section 3) and to evaluate technology assignments in the beach areas (Section 8). These composite data are provided in the project database.

2.2.2 FS Baseline Subsurface Sediment Data

Data from cores collected by six parties since the finalization of the RI baseline dataset were added to the subsurface sediment table in the FS baseline dataset. These parties include both public agencies and private companies:

- The Boeing Company collected 355 samples in 2008 and 2009 along the western boundary of the Boeing Plant 2/Jorgensen Forge EAA and under the historical overwater Plant 2 building to further characterize this EAA.
- PACCAR collected 25 samples in 2008 at RM 3.9 to 4.0E (8801 East Marginal Way) in support of its work under a MTCA cleanup order.
- The City of Seattle collected 38 samples in 2006 and 2008 in the Slip 4 EAA as part of its design work for this EAA.

- The Port of Seattle collected 11 samples in 2008 at Terminal 115 (RM 1.8W) for dredged material characterization to support berth modifications.
- USACE collected 32 samples in 1990, 1991, and 1996 to characterize material to be dredged from the navigation channel and collected 44 samples in 2008 and 2009 to support 2010 dredging. The data from the 1990s events were not included in the RI baseline dataset but have been added to the FS baseline dataset because they were used as lines of evidence for the bed composition model (BCM) upstream input parameters (see Section 5 and Appendix C).
- Delta Marine collected 4 samples at RM 4.2W in 2007 to support dredged material characterization for maintenance and deepening of the berthing area.

Table 2-2 describes each of these sampling events. These events resulted in 174 surface sediment and 509 subsurface sediment samples being added to the FS baseline dataset. Because some of these newer data replaced older data (on an individual contaminant basis), the surface sediment sample count for each one is not 174 greater than that for each contaminant in the RI baseline dataset. Table 2-3 provides the sample counts for each of the human health risk drivers.

These data were collectively used to refine the understanding of the nature and extent of contamination. These refinements were the basis for defining the areas of potential concern (AOPCs; Section 6) and for developing the remedial alternatives (Section 8). The newer data filled some data gaps but did not result in significant changes to the CSM.

2.2.3 Other Datasets Used in the FS

The FS baseline surface and subsurface sediment datasets described above were used to map the nature and extent of contamination in the LDW, to evaluate the remedial alternatives, and to estimate dredging volumes. Those datasets are included in several tables in a Microsoft Access file (FS project database) that accompanies this FS. Each table and dataset included in the FS project database has undergone rigorous quality control checks, as documented in technical memoranda (the most recent being Addendum 3; Windward 2012, review in progress).

Other datasets are also included in the project files, but have not been formatted into the standardized set of fields included in the project database. These files are provided in Microsoft Excel format (often maintained in the same format in which they were received) and have not undergone the same level of quality control checks as the database files. The FS project database and all accompanying Excel files are available on http://www.ldwg.org in one zip file. The zip file also contains an index describing each dataset and its file location. Table 2-5 lists the other datasets that were used as part of the FS.

In 2009 and 2010 (after the RI was finalized), LDWG collected composite surface sediment samples from each of six beach play areas. Because these data did not represent individual locations, they were not used in the FS baseline surface sediment interpolations. However, these data were used in risk calculations described in Section 3 and Appendix B. These data were also used to identify beach play areas potentially subject to active remediation. Appendix B provides maps showing the locations where these samples were collected. These data underwent rigorous quality control checks and are included in the FS project database.

The BCM, discussed in Section 5, was used to evaluate the potential for surface sediment to recovery naturally. Several datasets were used to characterize the contaminant concentrations associated with inputs from lateral and upstream sources. The datasets used to characterize lateral sources included CSO whole-water samples and storm drain solids samples[5] collected within the LDW drainage basin. The datasets used to characterize the contaminant concentrations associated with upstream inputs included dredged material characterization cores collected in the most upstream portion of the LDW navigation channel, surface sediment samples and solids from centrifuged water samples collected upstream of the LDW (many collected by Ecology), and whole-water samples collected by King County upstream of the LDW. All of these datasets are discussed in Appendix C, Part 3, and all except the upstream data collected by Ecology were presented in the RI (Windward 2010). Depending on the nature and source of each dataset, some of these datasets underwent independent quality control checks while others did not. All of these data are included in the FS project data files. An index that accompanies the data submittal (FS project database and accompanying Excel files) indicates where each dataset can be found.

Natural background concentrations of certain contaminants were estimated from a statistical evaluation of surface sediment data collected from Puget Sound. The DMMP agencies collected these data in 2008 during the Puget Sound sediment PCB and dioxin survey (*OSV Bold* Survey; EPA 2008b and DMMP 2009b). These data are discussed in Section 4 of the FS for the development of preliminary remediation goals and are included in a project Excel file, as part of the FS data submittal.

The recontamination potential of remediated sediments is evaluated in Appendix J using sediment time trend data collected within the LDW (Norfolk Area EAA, Duwamish/Diagonal EAA and adjacent enhanced natural recovery [ENR] area, and

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[5] Some of these solid samples were collected from drain lines that contain both CSO and separated stormwater inputs.

post-maintenance dredging surface sediment data from the FS baseline dataset) and from surface sediment data collected in the greater Puget Sound area (urban water body data, Dredged Material Management Program [DMMP] characterization of dioxins/furans, and RI samples collected offshore of greater Seattle area outfalls). These datasets are described in Appendix J. All of these datasets, except the urban water body and DMMP data, are in the FS project database. The other two datasets are in project Excel files.

Long-term surface sediment monitoring data from the perimeter of the Duwamish/Diagonal EAA were also used in this FS to evaluate time trends (recovery potential, see Appendix F). Because the perimeter monitoring locations are outside of the EAA, the most recent data are in the FS baseline dataset. The older resampled data are contained within a separate table in the FS project database. Long-term monitoring data (through 2009) from the Duwamish/Diagonal EAA, adjacent ENR area, and perimeter are also discussed in Section 7 to provide case-study information of remedial technologies used in the LDW.

Resampled locations that were removed from the FS baseline dataset as a result of data trumping were often used to evaluate the potential for natural recovery. Data for the paired locations (older and newer data) are provided in the FS project database, in a separate table. This table has a different format than other tables containing sediment data because the table pairs data from older and newer samples at each re-occupied location.

LDW tissue data were used for seafood consumption risk estimates in the HHRA (Windward 2007b) and have undergone quality checks. These data are included in both the RI and FS project databases. In addition, LDW tissue data collected in 2006 and 2007 are included in the project databases. Tissue data collected from Puget Sound and used for background calculations are discussed in Appendix B. These data are provided in a separate Excel table in the FS data files.

Seep and porewater data collected by LDWG and presented in the RI were compared to water quality criteria in Section 4 of this FS. These data are also discussed in Appendix N of this FS and are provided in both the RI and the FS project databases (Access files).

2.3 Conceptual Site Model (CSM)

The CSM for the LDW describes the physical and chemical conditions of the study area. The physical CSM describes the LDW in terms of three reaches: Reach 1 in the downstream portion of the LDW, Reach 2 in the middle, and Reach 3 in the upstream portion. Each reach has three distinct segments: a shallow (intertidal) bench area, a deep (subtidal) bench area, and the navigation channel. The three reaches were determined based on geomorphology and sediment dynamics, as described in Section 2.3.1.

The chemical CSM, which is discussed in Section 2.3.2, describes the distribution of contaminants of concern (COCs), specifically the risk drivers, in sediment. Sediment with the highest concentrations of risk drivers is not distributed uniformly across the LDW, but rather occurs in concentrated areas (e.g., EAAs). In depositional areas, higher contaminant concentrations are buried in the subsurface sediment by lower-concentration surface sediment originating from the upstream Green/Duwamish River. This aspect of the chemical CSM, along with a few notable exceptions, is discussed further in Section 5.

The CSM also identifies the potential sources of contaminants and the pathways by which contaminants may reach the LDW surface sediments and interact with receptors. A CSM generally incorporates information about sources, transport pathways, exposure pathways, and receptors and can be a valuable tool for evaluating the potential effectiveness of cleanup alternatives. The sources and transport pathways are discussed in Section 2.3.3. The exposure pathways and receptors are discussed in Section 3.

2.3.1 Physical CSM (Sediment Dynamics)

Sediment dynamics have been quantified through two sequential sediment transport models, with results published in the *Sediment Transport Analysis Report* (STAR; Windward and QEA 2008) and the *Sediment Transport Modeling Report* (STM; QEA 2008). The STAR, which documents the hydrodynamics related to water flow, identified three CSM reaches in the LDW, taking into consideration the geomorphology, extent of the saltwater wedge, and relative scour potential. The STM, which documents the movement of sediment (related to scour, deposition, and transport patterns), was then used to refine the CSM.

The STM (QEA 2008) built on the results of the hydrodynamic model and quantified sediment loading from different sources to each grid cell of the model domain (and from grid cell to grid cell) over time. Upstream river flow data spanning a 21-year period (1960 to 1980) were used to calibrate the STM. These data were used to establish the boundary conditions (i.e., upstream sediment load, hydrograph flow events, net sedimentation, and scour) used in model simulations (see QEA 2008, Appendix B). The movement of suspended and bed load sediment into the LDW from upstream and through the LDW was modeled over a 30-year (1960 to 1989) period. Average river flows were estimated to be 1,340 cfs, while river flows during the 100-year high-flow events are about 12,000 cfs (QEA 2008). Estimates of lateral inflows to the LDW from storm drains, CSOs, and streams were based on recent data collected by the City of Seattle and King County (QEA 2008, SPU 2008).

Results of the hydrodynamic and sediment transport modeling indicate that the LDW can be broadly separated into three reaches during high-flow conditions (shown in Figures 2-8a through 2-8c):

- Reach 1 is downstream (north) of RM 2.2 and is occupied by the saltwater wedge during all flow and tidal conditions. Sedimentation rates are variable; although this reach is net depositional in both the navigation channel and the adjacent bench areas. In the navigation channel, sedimentation rates vary from intermediate to high, with a small area near RM 0.8 to RM 0.9 having lower deposition rates. Net sedimentation rates on the benches are also intermediate to high, with two small areas having lower deposition. Empirical data show that the intertidal areas have relatively low net sedimentation rates, on the order of 0.5 cm/year. This reach is not likely to be subject to scour during the 100-year, spring-tide, high-flow event except in a few localized areas.
- Reach 2 extends from approximately RM 2.2 to RM 4.0 and includes the toe of the saltwater wedge during high-flow events; the saltwater wedge extends even farther upstream during average-flow conditions. The toe of the saltwater wedge is pushed downstream of this reach (to RM 1.8) only during extreme flow events (100-year, high-flow event and greater). Reach 2 is subject to some scour during high-flow events but is net depositional on annual time scales. Net deposition rates are spatially variable within this reach.
- Reach 3 extends from RM 4.0 upstream to RM 5.0. Flow in portions of this reach is characteristic of a freshwater tidal river during high-flow events. This reach is occupied by the saltwater wedge only during low- and average-flow conditions. This reach is also net depositional on annual time scales. Both the model and empirical data indicate that the navigation channel and Upper Turning Basin located in Reach 3 have higher net sedimentation rates than other areas of the LDW. Greater episodic erosion may occur in this reach than in the other reaches during high-flow events.

The STM (QEA 2008) also evaluated three physical processes significant for the FS: 1) bed stability related to scour potential from high-flow events and passing ship traffic, 2) net sedimentation rates, and 3) solids loading into and out of each model grid cell in the LDW. The sediments within each model grid cell are the result of these processes, and represent contributions from upstream sources, from within the LDW, and from lateral sources, collectively defined as bed composition. These processes are discussed in the following subsections.

2.3.1.1 Sediment Bed Stability and Scour Potential

Scour of bed sediment materials can be caused on a reach-wide scale by river discharge during high-flow events (i.e., high-flow-induced scour, see Figure 2-9) and by vessel traffic moving along the navigation channel. On localized scales, scour can occur as a result of vessel maneuvers in berthing areas (Figure 2-10). These three types of scour are discussed below.

High-Flow-Induced Scour

Scour of surface sediment as a result of high-flow events is a quantifiable disturbance. Based on historical data, high-flow periods are more tempered now than before construction of the Howard Hanson Dam. However, high-flow-induced scour events still occur when upstream inflow increases.

For the STAR (Windward and QEA 2008), field-derived erosion property data were collected from near-surface sediment within the LDW, and an analysis of natural erosion events was performed. The analysis focused on bed stability during episodic 2-, 10-, and 100-year high-flow events, which correspond to flows of 8,400, 10,800, and 12,000 cfs, respectively. In contrast, average flows are estimated to be 1,340 cfs.

Erosion rates as a function of shear stress and depth in the sediment bed were assessed in a laboratory using sediment cores collected from the LDW. Erosion rate tests were conducted using Sedflume, a device that gauges gross erosion rates over a range of shear stresses at various depths in a sediment core. These tests were used to predict erosion rates and critical shear stresses necessary to result in resuspension under various flow conditions. The relationship between shear stress and erosion rate was used to identify areas in the LDW that could potentially experience erosion under Green/Duwamish River discharge conditions ranging from average flow to the 100-year high-flow event. The general findings identified by the STAR (Windward and QEA 2008) and updated in the STM (QEA 2008) are summarized below:

- During all flow conditions, bed shear stress tends to be higher in the navigation channel than in the bench areas.
- During high-flow events in Reach 1, negligible bed scour occurs in most of the area downstream of RM 1.8. The denser saltwater wedge acts as a layer of protection against the high-flow velocities occurring above the salt wedge.
- During high-flow events in Reaches 2 and 3 (i.e., upstream of the saltwater wedge):
    - Generally, higher excess shear stresses occur in the navigation channel than on the benches for a given high-flow event and tidal condition.

- Minor differences exist in the general spatial pattern of excess shear stress during ebb and flood tides. Bed shear stresses are higher during spring tides than during neap tides.[6]
- Within the portions of the bench areas where erosion was predicted to occur, the potential for erosion tends to be highest near the navigation channel and tends to decrease toward the shoreline.
- Reach 3 tends to have higher excess shear stress values than the other reaches, but it also has higher sedimentation rates.

Overall, the maximum net erosion depth during a 100-year high-flow event is 22 cm, occurring in and just west of the navigation channel at RM 3.1 (Figure 2-11). Areas with high-flow scour exceeding 10 cm occur in scattered locations upstream of RM 2.9. See Section 5 for a discussion of model uncertainty related to the STM.

Ship-Induced Bed Scour from Passing Vessels Transiting the Navigation Channel

Propeller wash from vessels can produce increased bottom shear stress and, as a result, localized scour in some cases. The depth to which the erosion will occur varies with the velocity of the vessel, sediment type, and duration and frequency of the event. Propeller wash effects are generally proportional to the size, draft, and power of vessels; larger, deeper, and more powerful vessels exhibit propeller wash effects to greater depths. Propeller wash effects are most evident where navigation activity is concentrated, and where water depths are shallow and matched to the size of the vessels using the channels and berths.

The STAR (Windward and QEA 2008) reported the predicted results of a screening-level evaluation of transiting vessels in the navigation channel and their ship-induced bed scour, using parameters from two active, representative tugboats in the LDW, the *J.T. Quigg* and the *Sea Valiant*.[7] The results from the STAR and STM (Windward and QEA 2008, QEA 2008) are summarized as follows:

♦ Within the navigation channel, ship movement at the speed limit of 5 knots causes an average bed scour depth of less than 1 cm (and a maximum depth of 1 cm) per ship passage in Reach 1 and an average bed scour depth of less than 0.1 cm (and a maximum depth of 0.3 cm) per ship passage in

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[6] Spring tides occur during full- and no-moon phases, and the difference between higher high tide and lower low tide is maximum. Neap tides occur during the first and third quarters of the lunar cycle, and the difference between tide heights is minimal. Tides also vary with the solar cycle, with the amplitude being greatest (highest highs and the lowest lows) during the summer and winter solstices.

[7] These vessels are representative of those working in the LDW. Each ship has an open wheel propeller. The *J.T. Quigg* is a 100-ft long, 3,000-horsepower vessel. The *Sea Valiant* is a 128-ft long, 5,750-horsepower vessel.

Reaches 2 and 3. Within the bench areas, each ship movement at the speed limit of 5 knots can cause an average bed scour of about 1 to 2 cm in Reach 1 and less than 1 cm in Reaches 2 and 3.

- Reducing ship speed from the LDW speed limit of 5 knots to 2.5 knots significantly reduces bed scour, with predicted bed scour of less than 1 cm throughout the LDW for all conditions. Doubling the applied ship power has minimal effect on predicted scour depth. The typical vessel speed in the LDW is 2 to 3 knots (Riley, personal communication, 2006; Takasaki, personal communication, 2006).
- The reworked (i.e., mixed) sediment layer is equated with the depth of gross bed scour, based on the assumption that the same layer is continually reworked. The upper-bound estimate is less than a 10-cm depth. The most-downstream reach (Reach 1) was estimated to have an upper-bound average scour thickness of less than about 1 cm in the navigation channel and about 1 to 2 cm in bench areas. In the middle and upstream reaches (Reaches 2 and 3), the reworked sediment layer was estimated to have an upper-bound average thickness of less than 0.1 cm in the navigation channel and less than 1 cm in bench areas. The frequency of mixing is about 100 to 250 events per year.
- Bed scour by passing vessels does not have a significant effect on the erosion rate properties at particular locations in the bench areas or navigation channel of the LDW. These areas are conceptually displayed in a series of CSM figures (Figures 2-8a through 2-8c).

The effects of ship-induced bed scour are incorporated into the present structure of the LDW sediment bed because ship movement has been occurring for at least the past 40 years (Windward and QEA 2008). Ship-induced bed scour is viewed as an impulsive erosion-deposition process that tends to behave like an ongoing, small-scale, shallow mixing process for surficial bed sediment. Scour by transiting ships is not a significant sediment transport mechanism because it's estimated to occur in few grid cells, and where scour is estimated, the depth is shallow (less than 1 cm per ship passage in Reach 1 [RM 0 to RM 2.2], and less than 0.1 cm per ship passage in Reach 2 [RM 2.2 to RM 4.0]). The estimated scour depth is within the top 10 cm active mixing layer, and is therefore merely another mixing process within that zone. It is not a significant transport mechanism relative to the other active mixing processes. This analysis reviewed only transiting vessels, not vessels maneuvering at berthing areas (see below for maneuvering vessels).

Ship-Induced Bed Scour from Maneuvering Vessels

Ship-induced bed scour from vessel maneuvers near berthing areas was primarily evaluated on a spatial basis by examining sun-illumination-manipulated bathymetry maps (presented here) and was also evaluated by modeling (presented in Appendix C Part 7). Multi-beam bathymetric soundings were recorded for the RI in 2003 by David Evans and Associates (DEA) (Windward and DEA 2004). The soundings were converted into a digital terrain model of the 3-dimensional mudline elevation in ft MLLW. Sun-illumination (or hillshade) maps were then generated from the processed bathymetry file. Highlighting or shading emphasizes fine-scale features that would otherwise be missed using standard digitizing methods. This process, often referred to as hillshading, is a hypothetical illumination of a surface according to a specified azimuth and altitude for the sun. This creates exaggerated vertical scales and allows for better visualization of vertical relief features in the sediment bed. Where features are identified visually, a geographic information system (GIS) can be used to estimate the vertical scale (e.g., depth of a scour feature) by displaying the values of adjacent bathymetric readings.

By applying hillshading techniques to the bathymetric data, various bed forms are evident in and near the berthing areas. These bed forms include V-shaped, symmetrical, and asymmetrical depressions oriented in various directions (Figure 2-10). The sun-illumination maps for the LDW were visually inspected to identify areas with steep gradients or ridges and furrows, interpreted as ship-induced scour. In some cases, the bottom features show depressions where barges have been resting in the mud during low tide and mounds where barges have been secured/moved by lowering steel rods or "spuds" into the mud.

The entire LDW was reviewed for scour, but mapping of this layer was generally restricted to areas where active berthing (vessels and overwater structures as documented in 2002 Port Series No. 36 publication [USACE 2002]) was observed. Active berthing was described as higher-traffic areas based on the presence of a pier/wharf face (discussed in Section 2.6.3), documented maintenance dredging events, aerial photographs showing moored barges or other vessels, adequate water depths, and/or operator interviews indicating that the area supports frequent vessel traffic. Vessels maneuvering into these areas may be causing scour. Vessel traffic patterns are discussed in Section 2.6.6. All of these lines of evidence were collectively used to define and map the vessel scour footprint.

Additionally, in the navigation channel, smaller features oriented with the axis of the channel are evident. It is important to note that although these bed forms are evident in many areas of the LDW and their depths vary from a few cm to over 30 cm in some areas, the majority of scour marks appear to have depths of less than 10 cm (i.e., within the depth of the active mixing zone). These smaller features in the navigation channel may represent effects of tug maneuvering to position vessels into berthing areas. This analysis provides information on net scour, but not on absolute scour occurring during individual events. Areas that are scoured as vessels maneuver may immediately fill in as the sides of the trench are sloughed. Therefore, an observed net depth of 10 cm may not capture deeper immediate scour depths. Areas with more than 10 cm of relief (forming ridges and furrows in the sediment surface) are primarily associated with berthing areas, where tugs maneuver barges, bulk carriers, and container ships. As a point of comparison, the STM (QEA 2008) predicts a maximum 100-year high-flow net erosion depth of 22 cm.

These anthropogenic bedform features are dynamic; old features are filled in by sedimentation and/or reworked by the creation of new features. This analysis represents a "snapshot" in time (2003) that is coincident with collection of the bathymetric data and provides only a general pattern of vessel scour. Detailed evaluations of vessel scour are more appropriate on a location-specific basis. This analysis is considered to be representative of ambient conditions.

2.3.1.2 Net Sedimentation Rates

Net sedimentation rates were determined in the STM (QEA 2008) and validated using empirical evidence from the RI and historical cores. The STM quantified sedimentation rates on a grid-cell basis using bed sediment properties (e.g., grain size and scour potential) and incoming total suspended solids (TSS) and bed loads (Figure 2-11[8]).

Results of the predictive model and empirical geochronology analysis are summarized as follows (QEA 2008):

- Net sedimentation rates in the intertidal and subtidal bench areas were estimated to range from 0.2 cm/year to greater than 2.0 cm/year, with those in the intertidal areas being on the order of 0.5 cm/year. The cores having lower estimated net sedimentation rates were generally collected from areas with shallower water depths (i.e., intertidal elevations above -4 ft MLLW) than the other geochronology cores, suggesting that these areas may be subject to relatively low deposition.

- Net sedimentation rates in the navigation channel exceeded 2 cm/year, reaching up to >50 cm/year in the Upper Turning Basin, where the maximum estimated net sedimentation rate was 150 cm/year. The Upper Turning Basin behaves as a trap for sediment entering the LDW from upstream and is dredged on an approximate biennial schedule to remove accumulated sediment. If the Upper Turning Basin were not dredged

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[8] Figures 5-4 and F-2 compare net sedimentation rates estimated from cores with those predicted by the STM.

periodically, net sedimentation rates would likely be lower because some of the sediment would move farther downstream before depositing. This would likely increase net sedimentation rates in areas downstream of the Upper Turning Basin.

- Evidence of potential disturbances (e.g., episodic erosion and deposition, dredging, slumping) was observed in some of the geochronology cores.

Empirical evidence of net sedimentation rates, as reported in Appendix F of the STAR (Windward and QEA 2008), including chemical and physical time markers identified in sediment cores collected in the LDW, was used to validate the net sedimentation rates in the STM (QEA 2008). In most of the cores, there is generally strong agreement between the empirical lines of evidence and the STM estimates. However, in some locations, the STM estimates greater sedimentation than the empirical evidence does, and in other locations, the reverse occurs. This is discussed in more detail in Appendix F of this FS. Areas with lower net sedimentation rates (less than 2 cm/year) are scattered throughout the LDW, as dictated by channel geography, intertidal areas, and near-field scour events. Some uncertainty may exist in the observed vertical profiles of cores, but generally the empirical evidence supports the findings from the STM (QEA 2008).

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

An understanding of the distribution of COC concentrations in the LDW follows the development of the physical CSM (Section 2.3.1).

2.3.2.1 COC Concentrations

The baseline HHRA (Windward 2007b) identified four human health risk drivers: PCBs, arsenic, cPAHs, and dioxins/furans. These risk drivers are evaluated in this FS at three spatial scales appropriate to human exposure: site-wide (netfishing), in potential clamming areas, and in beach play areas. Further, 41 of the 47 contaminants (including total PCBs and arsenic), for which SMS criteria are available, are risk drivers for benthic invertebrates because detected concentrations of these contaminants in surface sediments exceeded SMS criteria at one or more sediment stations (these data are hereinafter referred to as SMS chemistry data). SMS contaminants are evaluated on a point basis, as relevant to benthic invertebrate exposure. Total PCBs are also a risk driver for river otters and are evaluated on a site-wide basis for this receptor. Section 3 provides a summary of the ERA, HHRA, including the COCs, risk drivers, and appropriate exposure scales.

Tables 2-3 and 2-6 summarize minimum and maximum detections, average concentrations, and detection frequencies of human health risk drivers and other COCs, respectively, in the LDW FS dataset. In both the RI and FS baseline datasets, total PCBs were detected at 94% of the locations where PCB Aroclors were analyzed. In the RI baseline dataset, detected total PCB concentrations ranged from 1.6 to

223,000[9] micrograms per kilogram dry weight (µg/kg dw). In the FS baseline dataset, concentrations ranged from 2.2 to 2,900,000 µg/kg dw. Two samples with total PCB concentrations of 2,900,000 and 230,000 µg/kg dw were excluded from the spatial interpolation as outliers. Arsenic was detected at 93% and 94% of the locations where arsenic was analyzed in the RI and FS baseline datasets, respectively. In both datasets, the range of detected arsenic concentrations was 1.2 to 1,100 milligrams per kilogram dry weight (mg/kg dw), and the mean was 17 mg/kg dw. cPAHs were detected at 94% and 96% of the locations where cPAHs were analyzed in the RI and FS baseline datasets, respectively. In both datasets, the maximum cPAH concentration was 11,000 micrograms toxic equivalent per kilogram dry weight (µg TEQ/kg dw). The minimum detected cPAH concentration was the same in both the FS and RI datasets (9.7 µg TEQ/kg dw) and the mean concentration was lower in the FS baseline dataset than in the RI baseline dataset (460 µg TEQ/kg dw versus 500 µg TEQ/kg dw). Contaminants with SMS exceedances (Table 2-6) are represented only as point concentrations in the FS, while total PCBs, cPAHs, dioxins/furans, and arsenic are represented both as point concentrations and as spatially-weighted average concentrations (SWACs).

The FS baseline SWAC for total PCBs is 346 µg/kg dw[10] compared to the RI baseline SWAC of 350 µg/kg dw.[11] The FS baseline SWAC for cPAHs is 388 µg toxic equivalent (TEQ)/kg dw, compared to the RI baseline SWAC of 380 µg TEQ/kg dw. The FS baseline SWAC for arsenic is 15.6 mg/kg dw based on inverse distance weighting (IDW) interpolation, discussed below. The RI baseline SWAC for arsenic was 15 mg/kg dw, see Section 4 of the RI for all risk drivers; Windward 2010.

Dioxins/furans were detected in all surface sediment samples in which they were analyzed. The LDW-wide baseline SWAC (based on Thiessen polygons) is 25.6 nanograms (ng) TEQ/kg dw. Dioxins/furans were not spatially interpolated in the RI. The average of the 54 dioxin/furan surface sediment samples in the RI baseline dataset was 82 ng TEQ/kg dw (Windward 2010). A total of 119 surface sediment samples with dioxin/furan data are in the FS baseline dataset. Following finalization of the RI baseline dataset in 2006, additional dioxin/furan surface sediment samples were

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[9] This value was rounded to 220,000 µg/kg dw for presentation in the RI.

[10] Two outliers in the Trotsky inlet (RM 2.2) were not used in the interpolation to generate this LDW-wide SWAC. When all FS baseline data are considered, the SWAC is 1,313 µg/kg dw. These two outlier samples were not in the RI baseline dataset because those data were not available until after that dataset was finalized.

[11] The FS and RI SWACs are not calculated over the same area. For the FS, baseline SWACs were calculated over the area extending from RM 0.0 to RM 5.0. For the RI, baseline SWACs were generally calculated over the area from RM 0.0 to RM 6.0.

collected in 2009 and 2010, which are described in Table 2-2 and in the memorandum *2009/2010 Surface Sediment Sampling Results for Dioxins and Furans* (Windward 2010a).

For the SMS chemistry data, a total of 633 locations (44% of the 1,438 FS baseline surface sediment locations from RM 0.0 to 5.0) had detected concentrations of at least one SMS contaminant that exceeded the sediment quality standard (SQS) of the SMS. For some of these locations, the exceedances are only for total PCBs, being the only contaminant analyzed in those samples. Approximately half (316) of the locations with exceedances of SMS criteria are in EAAs. Outside of the EAAs, 317 sampling locations had surface sediment chemistry data that exceeded the SQS, based on chemistry alone.[12]

Sediment toxicity tests were conducted on surface sediment samples collected by LDWG from 48 locations for the RI. Thirty additional surface sediment samples were collected during the Ecology SPI event and subjected to toxicity testing. Two of the RI toxicity samples were co-located with newer toxicity data in the FS baseline dataset. Therefore, these older toxicity data were removed from the FS baseline dataset, yielding a total of 76 toxicity samples,[13] 44 of which passed for all biological endpoints tested. Of these 44 locations passing the toxicity tests, 41 represented either SQS or cleanup screening level (CSL) exceedances based only on chemistry. When evaluating surface sediment data relative to SMS exceedances, toxicity testing results override chemistry results. However, the chemistry data are retained for other FS purposes, such as mapping of human health risk drivers and source control evaluations. These 41 locations with toxicity passes, but chemistry exceedances, were identified as being below the SQS for mapping purposes.

Figures 2-12a through 2-12e display the exceedances of the SQS or CSL for any SMS contaminant in each sample of each core. Tables in Appendix G (Tables G-1 to G-3) list the SMS contaminants, and the concentrations responsible for those exceedances. It

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[12] One SMS contaminant, 2,4-dimethylphenol, was not identified as a benthic risk driver in the RI (Windward 2010) and ERA (Windward 2007a) because it did not exceed the SQS in the RI baseline dataset. However, this contaminant exceeded the SQS and CSL (which are both 29 µg/kg dw) in the Ecology SPI event. This contaminant was detected above the SQS and CSL in 25 of 30 SPI event samples. However, 20 of these samples have toxicity data passing the SQS biological effects criteria, so they are not considered SQS exceedances, following the data rules.

[13] One 2005 Round 2 RI location where toxicity data are available is co-located with a 2003 Duwamish/Diagonal EAA perimeter monitoring location. The chemistry data for this Round 2 location are not in the FS baseline dataset (because in the RI baseline this location was described as being influenced by the EAA removal activities and thus did not represent baseline conditions). However, to expand the toxicity dataset, the toxicity test results for this location (LDW-SS22) were used in the FS baseline dataset. This is more protective, because the 2003 chemistry results are below the SQS, but the 2005 toxicity test result is a CSL exceedance; therefore, this location is coded as exceeding the CSL.

should be noted that there are no toxicity test overrides for subsurface sediment data. The following observations were made regarding these subsurface sediment data:

- Forty-eight percent (728 of 1,504) of the subsurface sediment samples analyzed for PCBs had detected total PCB concentrations above the SQS.
- Five percent (28 of 531) of the subsurface sediment samples analyzed for arsenic had detected concentrations above the SQS.
- Twenty-five percent (81 of 535) of the subsurface sediment samples analyzed for bis(2-ethylhexyl) phthalate (BEHP) had detected concentrations above the SQS. Although BEHP is not a human health risk driver, it is being mapped because, other than total PCBs (515), it has the most SQS exceedances (104) in the surface sediment dataset (Table 2-6).
- Forty-nine percent (785 of 1,585) of the subsurface sediment samples had detected concentrations above the SQS for at least one of the SMS contaminants.

In general, the average concentrations of total PCBs and arsenic are higher in subsurface sediments than in surface sediments, while the reverse is true for cPAHs and dioxins/furans (Table 2-3). However, it is noted that concentrations in surface sediment are more appropriately compared to concentrations in subsurface sediment on a core-by-core basis. Core-by-core comparisons are provided in Appendix F as part of the discussion of empirical evidence for natural recovery.

2.3.2.2 Interpolative Mapping of Risk-Driver Contaminants

Spatially interpolated data are used in this FS for several evaluations, including the estimation of contaminated sediment volumes, natural recovery modeling, and delineation of the AOPCs (as discussed in Section 6). This section provides additional detail on the methods of spatially interpolating surface sediment data for the risk drivers, using the FS baseline dataset. Spatial interpolation of data generates a value for every location within the study area, rather than only at the discrete locations sampled. This interpolation is especially important for chemistry data that are applied to site-wide exposure scenarios and used as model inputs. Uncertainty related to spatial interpolation is also discussed in Section 6.

Human Health Risk-Driver Contaminants

The FS baseline dataset includes the following surface sediment sample counts between RMs 0 and 5.0: total PCB data for 1,392 stations, arsenic data for 916 stations, and cPAH data for 891 stations. For these three human health risk drivers, the data were spatially interpolated to generate a network of continuous 10-ft^2 grid cells. The IDW method used for the interpolations applies adjustable parameters to create the grid-based output for the whole LDW area. The parameters chosen and the methods used to optimize these parameters are discussed in Appendix A. The resulting IDW interpolations for total PCBs, arsenic, and cPAHs are displayed in Figures 2-13 through 2-15.

There are 119 discrete surface sediment grab samples for dioxins/furans included in the FS baseline dataset for interpolation.[14] Thiessen polygons were selected as the method for spatially representing these surface sediment data across the study area because the dataset is relatively small compared to that for the other risk drivers. The use of Thiessen polygons is a method by which a polygon is drawn around every data point. The boundaries of each polygon are drawn at the mid-points between the data point of interest and each surrounding data point. All surface sediment within each polygon is then assigned the concentration of the empirical data point contained within it; thus, a spatial extent is assigned to sample data at a given location. This method has inherent uncertainty because, unlike IDW interpolation, a concentration gradient is not estimated between data points. However, IDW interpolation is not appropriate for dioxins/furans because of the sparse dataset, as discussed in Appendix A. The dioxin/furan data for surface samples in the FS baseline dataset are shown in Figure 2-16; the dioxin/furan data for subsurface samples, as well as the Thiessen polygons mapped for the surface sediment data, are shown on Figure 2-17.

Interpolated data for total PCBs, arsenic, cPAHs, and dioxins/furans are used in the BCM (discussed in Section 5) to predict surface sediment quality over time.

SMS Chemistry

Thiessen polygons were also selected to spatially represent exceedance status relative to SMS criteria for chemistry and toxicity data at each location. There are 1,438 surface sediment samples with SMS contaminant data. However, some of these samples were analyzed only for PCBs. Of these samples, 891 were analyzed for all SMS contaminants (or the majority of the SMS contaminants), and thus this smaller dataset was used to delineate the spatial extent of SMS exceedances.

A polygon with more than one data point contained within it (e.g., one station with SMS chemistry data and a second station with only PCB data) was assigned the highest exceedance status of the two stations (pass, SQS, or CSL). The maximum exceedance status for individual SMS contaminants at each station was used to assign a status to that station's Thiessen polygon. For example, the polygon around a station with a CSL exceedance for fluoranthene, SQS exceedances for four other PAHs, and no exceedances for any other SMS contaminants, was designated as exceeding the CSL.

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[14] The composite sediment samples collected from beach areas were not included in the spatial interpolation of the baseline; but were included in Section 3 risk estimates and Section 8 technology assignments.

For mapping the AOPCs (Section 6) and remedial alternative footprints (Section 8), data are mapped as points with the spatial extent assigned by Thiessen polygons. The IDW method is not used because it is too labor intensive to interpolate the surface sediment concentrations of all SMS contaminants, which involves multiple steps of adjusting interpolation parameters and calculating error metrics for each set of parameters.

Where toxicity and chemistry data are both available within a polygon, toxicity results override chemistry results. For example, a polygon with a toxicity pass, but a chemical SQS exceedance, was assigned a pass. The toxicity data were used to assign the SMS status to the entire polygon, even if two stations are located within the polygon.[15] This override is relevant only to assigning exceedance status to Thiessen polygons relative to the SMS; it does not exclude chemistry data from other evaluations, such as the IDW interpolation of total PCBs described above.

Figures 2-13 through 2-16 show the distributions of total PCBs, arsenic, cPAHs, and dioxins/furans in surface sediment, respectively. The distribution of BEHP surface sediment sample locations and concentrations is shown in Figure 2-18.[16] The distributions of SMS chemistry and toxicity data in the surface sediment are shown in Figure 2-19. Figures 2-20a through 2-20g display the SMS contaminant concentrations in both dry weight and organic-carbon normalized units, where appropriate, that exceeded the SQS. Figure 2-21 presents the interpolation of the SMS exceedance status (by Thiessen polygon) in surface sediment.

2.3.2.3 Contaminant Distribution Patterns

Based on the surface sediment data, the LDW can be characterized as having localized areas of relatively high contaminant concentrations ("hot spots") separated by relatively large areas with lower contaminant concentrations. The distribution of concentrations in these hot-spot areas were different among the risk drivers, as described below. The top one hundred samples with the highest total PCB concentrations (ranging from 2,970 to 2,900,000 µg/kg dw) were all collected from within and near the EAAs and other hot spots (Trotsky Inlet at RM 2.2W, RM 3.8E, and RM 1.0 in the navigation channel). The average total PCB concentration of the remaining samples outside of these areas is 307 µg/kg dw (1,292 samples excluding the top 100 concentrations and the samples above RM 5.0) compared to 1,136 µg/kg dw for 1,390 samples (excluding the two outlier samples). The average PCB concentration in the FS baseline dataset is 3,383 µg/kg dw with all 1,392 samples included.

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[15] Extrapolation of toxicity test results across stations for the purpose of defining AOPCs in the FS should not be construed to imply that this practice will be acceptable in defining cleanup areas in the remedial design phase.

[16] BEHP data are included in the evaluation of SQS exceedances (benthic invertebrate risk driver).

The highest arsenic concentrations are localized mostly within discrete areas at RM 0.1, RM 1.0 (Slip 1), RM 1.3 – 1.45 (in the vicinity of Glacier Northwest, Inc.), RM 2.2 (Slip 3) and RM 3.8E (Figure 2-14). Fourteen stations exceed the CSL for arsenic and are located in these areas. The average arsenic concentration, excluding these nine stations, is 12 mg/kg dw, compared to 16 mg/kg dw with all data (918 samples).

The samples with the highest cPAH concentrations are more widespread (Figure 2-15). There are 48 samples at or above 1,500 µg TEQ/kg dw. The average cPAH concentration, excluding these 48 stations, is 333 µg TEQ/kg dw, compared to 459 µg TEQ/kg dw with all data (891 samples).

The five highest dioxin/furan sample concentrations are located within an EAA and two hot-spot areas: one concentration of 180 ng TEQ/kg dw (Duwamish/Diagonal EAA); three concentrations of 460, 570, and 2,100 ng TEQ/kg dw at RM 1.5W; and 410 ng TEQ/kg dw in Trotsky Inlet (RM 2.2W) (Figures 2-16 and 2-17). All other dioxin/furan concentrations are at or below 120 ng TEQ/kg dw. The average dioxin/furan concentration, excluding the five highest concentrations, is 11 ng TEQ/kg dw, compared to 42 ng TEQ/kg dw with all data from RM 0 to 5 (119 samples).

The highest surface sediment concentrations of the human health risk drivers often co-occur, typically within the EAAs and other hot spots, as noted by area below:

- **Duwamish/Diagonal EAA**: Preremedy sediments in the Duwamish/Diagonal EAA contained some of the highest concentrations of three of the four human health risk drivers: total PCBs, cPAHs, and dioxins/furans. The fifth highest total PCB concentration in the FS baseline dataset (56,200 µg/kg dw) and the fifth highest dioxin/furan concentration (180 ng TEQ/kg dw) were collected in this area. Five of the cPAH samples collected in this EAA exceeded 1,500 µg TEQ/kg dw.
- **Terminal 117 and Boeing Plant 2/Jorgensen Forge EAAs**: Of the ten samples with the highest total PCB concentrations, five (26,000 to 110,000 µg/kg dw) were collected from the sediments in the Terminal 117 and Boeing Plant 2/Jorgensen Forge EAAs; four of the samples with the highest cPAH concentrations (3,400 to 11,000 µg TEQ/kg dw) were also from these areas. A sample with an elevated dioxin/furan concentration (101 ng TEQ/kg dw) was also collected in the Boeing Plant 2/Jorgensen Forge EAA.
- **Slip 4 EAA**: Thirteen total PCB samples exceeded 1,300 µg/kg dw, and 5 cPAH samples exceeded 1,500 µg TEQ/kg dw.
- **Norfolk EAA Area**: A sample downstream of the Norfolk Area at RM 4.85 had the third highest total PCB concentration (223,000 µg/kg dw).

- **Trotsky Inlet (RM 2.2W)**: The two highest concentrations of total PCBs (2,900,000 and 230,000 ⍰g/kg dw) were collected in 2007 at RM 2.2W (Trotsky Inlet; SAIC 2009). However, they were removed from the total PCB dataset as outliers for the purposes of IDW interpolation. These samples remain in the FS baseline dataset, but were excluded from the interpolation and any reported SWACs. The sample with the fourth highest dioxin/furan concentration (410 ng TEQ/kg dw) was also collected in the Trotsky Inlet.
- **RM 3.8E**: The highest arsenic concentration (1,100 mg/kg dw) was collected at RM 3.8E. This area also had elevated cPAH concentrations (>1,500 µg TEQ/kg dw).
- **Glacier Northwest, Inc. (RM 1.5W)**: Samples with the three highest dioxin/ furan concentrations (463, 565, and 2,100 ng TEQ/kg dw) were collected from sediments in the embayment adjacent to Glacier Northwest, Inc. (RM 1.5W). This embayment (and the downstream area to RM 1.3) also contained elevated arsenic concentrations (>93 mg/kg dw).

Some other areas in the LDW with high concentrations of co-located human health risk drivers include:

- The Ash Grove Cement Area (RM 0.1E) for arsenic, cPAHs, and total PCBs
- The head of Slip 1 for arsenic and cPAHs
- The navigation channel just upstream of RM 1.0 for total PCBs and dioxins/ furans.

Some areas listed in the bullets above exhibited high COC concentrations in both subsurface and surface sediment, coincident with low net sedimentation rates calculated in the STAR (Windward and QEA 2008) and supported by the STM (QEA 2008). In a few areas where higher net sedimentation rates were estimated, the presence of high COC concentrations near the surface could be the result of localized disturbances or recent, ongoing sources of contamination.

2.3.3 Sources and Pathways

After the physical and chemical settings are described, the third component of a CSM evaluates the source of the contaminants and the likely pathways by which these contaminants are transported into and within the LDW. Although the source control program and this FS address a much broader list of contaminants, this section focuses on the sources and pathways for the four human health risk drivers identified in the RI (Windward 2010).

2.3.3.1 Historical and Ongoing Sources of Contaminants

Today, many sources of historical origin, including direct discharges of municipal and industrial wastewater and spills, have been identified and controlled to some extent, by enhanced regulatory requirements, improved housekeeping practices, and technological advances. The reduction of some contaminants, such as PCBs, is due in part to banned production and use in the U.S.; however, significant contamination of historical origin is still present in the environment, and releases are ongoing. Such PCB legacies include older paints, caulks, and building materials still on or in existing structures, as well as soils and groundwater that were contaminated while PCBs were still actively used and produced in the U.S. Historical sources likely contributed much of the sediment contamination in the LDW, and historically impacted media/materials remain in the drainage basin and continue to be transported to the LDW.

Potential sources of PCBs, arsenic, PAHs, and dioxins/furans are summarized below:

- Although PCB production was banned in 1979, historical PCB use continues to affect the LDW today in a number of ways, including flaking paints, caulking, and building materials that contain PCBs and contaminated soils and groundwater. Historical sources of PCBs to the LDW include dielectric fluids, waste oils, hydraulic oils, paints, and sealants. PCBs were also historically released with cement kiln emissions, along with dioxins/furans. PCBs also come from industrial, commercial, and residential properties (e.g., hydraulic fluid in historical equipment). PCBs are present in the LDW drainage basin in sources such as contaminated soils and building materials such as paint and caulk (e.g., the former Rainier Brewery building, now known as Rainier Commons, which has paint on its exterior walls with total PCB concentrations greater than 10,000 mg/kg dw).

- Arsenic was historically (and is currently) used in lumber treatment and is released with other metals during watercraft repair. Arsenic was also released historically in air emissions from smelters, wood-treating facilities, and distillate oil combustion. Atmospheric releases of arsenic have been significantly minimized by the closure of smelters. Releases of arsenic and other metals to the LDW have been reduced by housekeeping practices and controls on wastewater discharge at facilities that practice activities such as ship maintenance.

- PAHs are generated from the burning of organic matter, fossil fuels, and charcoal (pyrogenic) and are present in refined petroleum products (petrogenic). Therefore, PAHs are continually generated and released to the LDW drainage basin and airshed through petroleum use and combustion. In addition, PAHs were historically released from brick manufacturing operations, hydraulic equipment manufacturing, machine shops, and from repair and fueling of vehicles, airplanes, trains, and watercraft. They can continue to be released by most of these sources; but best management practices (BMPs) controlling spills and leaks have reduced input from these sources. Finally, timber piles and dolphins (groups of closely driven piles used as a fender for a dock, a mooring, or a guide for boats) in the LDW and utility poles and railroad ties in the watershed were treated with creosote, which can deposit PAHs directly into the LDW as these structures degrade or onto impervious surfaces in the watershed.

- Dioxins/furans are not used in manufacturing operations but are unintentionally formed as byproducts of incineration when chlorine and organic material are present. They were historically (and are currently) released from the burning of waste and from paper mills, cement kilns, and drum recycling. Historically, dioxins/furans were byproducts of pentachlorophenol (used in wood treating) and pesticide production; neither activity is present in the LDW drainage basin today.

2.3.3.2 Pathways to the LDW

To identify and manage sources, it is important to understand sources (discussed above) and pathways to the LDW sediments. Contaminated media from within the LDW drainage basin can affect sediments in several ways, which can be organized into seven general types based on the affected media, the origin of contamination, and pathways to sediments:

- Direct discharge (e.g., CSOs, storm drains)
- Surface water runoff or sheet flow
- Spills and/or leaks to the ground, surface water, or directly into the LDW
- Groundwater migration/discharge
- Bank erosion/leaching
- Atmospheric deposition
- Transport of resuspended contaminated sediments.

These pathways, as they relate to the four human health risk drivers, are discussed in more detail below. Not all pathways are complete or significant at all locations or at all times. Ongoing sources include those associated with industrial and general urban use within the watershed. Examples of contaminants and their sources include PAHs (fossil fuels), phthalates (plastics), zinc (tire wear), and copper (brake pads). Ongoing sources also include legacy contamination from historical upland operations, which continue to impact the LDW via ongoing pathways, such as groundwater migration/discharge and bank erosion. Contaminants released to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the LDW through various pathways.

Historically, controls on wastewater discharges and use of BMPs were not common. PCB discharges in particular are expected to have been of a greater magnitude historically before commercial PCB production was banned in 1979. However, trends for other contaminants such as BEHP and PAHs suggest rising levels due to increased urbanization. Appendix F presents historical risk-driver trends in Puget Sound sediments, and Appendix J evaluates recontamination potential to the LDW by direct discharge pathways (CSOs and storm drains).

Direct Discharge

Discharge from public or private storm drain systems, CSOs, and emergency overflows (EOFs) is a pathway for contaminants to enter the LDW. The locations of CSOs and EOFs are displayed on Figure 2-22 (along with other outfalls and the source control areas discussed in Section 2.4). CSOs and EOFs can discharge wastewater (residential, commercial, and industrial) and stormwater runoff. CSO discharges generally occur only during large storm events when the capacity of the combined sewer system is exceeded and not all flow can be successfully conveyed to a treatment plant. EOF discharges are not storm-related; those overflows occur as a result of mechanical failure, pipe obstruction, or power failure. The LDW drainage basin is served by a combination of separated storm drains and sanitary sewers and combined sewer systems. The total combined (storm and sanitary) sewer service area is 19,800 acres. The separated storm drainage basin covers 8,936 acres. However, these areas overlap in many places; the total area discharging to the LDW is approximately 20,400 acres (Schmoyer, personal communication, 2011a). Approximately 208 direct discharge points occur along the LDW shoreline, of which 203 are public or private outfalls, and 5 are ditches, creeks, or streams. In addition, 7 major seeps and 22 abandoned outfalls have been identified during shoreline surveys (Schmoyer, personal communication, 2011b).

Stormwater pollution is generated when rain contacts pollutants that have accumulated in or on exposed soils and surfaces, or comes from illegal discharges or illicit connections to storm drains, which convey stormwater only. Storm drains convey stormwater runoff collected from streets, parking lots, roof drains, and other impervious surfaces to the LDW. A wide range of contaminants may become dissolved or suspended in stormwater as it flows over surfaces. Contaminated solids that collect in storm drains/pipes, ditches, or creeks may be carried to the LDW by stormwater. Activities in urban areas generate particulates, dust, oil, asphalt, rust, rubber, metals, pesticides, detergents, or other materials that can be flushed into storm drains during wet weather events. Storm drains also convey materials generated by business activities such as outdoor manufacturing, outdoor storage of equipment and waste materials, vehicle washing, runoff from landscaped areas, erosion of contaminated soil, groundwater infiltration, and illegal discharge of materials into the sewer. Some businesses have National Pollutant Discharge Elimination System (NPDES) industrial stormwater permits. In the LDW drainage basin, approximately 90 general and individual NPDES permits have been granted for industrial stormwater discharges to storm drains or the LDW. However, not all businesses in the stormwater drainage area are required to obtain such permits. The City of Seattle, City of Tukwila, the Port of Seattle, and King County are NPDES permittees for stormwater discharged via municipal outfalls.

Some areas of the LDW are served by combined sewer systems, which carry both stormwater and municipal/industrial wastewater in a single pipe. Under normal rainfall conditions, wastewater and stormwater are conveyed through this combined sewer pipe to a wastewater treatment facility. During large storm events, however, the total volume of wastewater and stormwater sometimes exceeds the conveyance and treatment capacity of the combined sewer system. When this occurs, the combined sewer system is designed to overflow through relief points, called CSOs. The CSOs prevent the combined sewer system from backing up and creating flooding problems. Untreated municipal and industrial wastewater and stormwater can be discharged through CSOs to the LDW during storm events. CSO discharges can carry contaminants that affect sediments. The City's CSO network has its own NPDES permit; the County's CSOs are administered under the NPDES permit established for the West Point Wastewater Treatment Plant.

Stormwater is discharged to the LDW from approximately 200 public and private storm drains, CSOs, ditches, and streams, and contaminants discharged from any of these may affect LDW sediments. Most of the waterfront properties within the LDW are served by privately-owned drainage systems that discharge stormwater directly to the LDW. Upland areas not adjacent to the waterway are served by a combination of privately- and publicly-owned drainage systems. However, the private storm drains in the upland areas typically connect to a publicly-owned system before discharging to the LDW. The City of Seattle and King County stormwater and CSO systems overlap throughout the LDW drainage basin in complex ways. The following paragraphs summarize characteristics of these various systems and outfalls in the LDW source area. Section 2.4 describes the source control strategy for addressing direct discharges from both public and private drainage systems in the LDW drainage basin.

The City of Seattle's storm drain system services approximately 61% of the LDW drainage basin (8,936 acres), which is a separated or partially separated storm drain system. Other public storm drains service about 24% of the drainage basin, and the remaining 15% of the drainage basin is serviced by small, private waterfront storm drain systems.

The City of Seattle owns and operates the local sanitary sewer collectors and trunk lines, while King County owns and operates the larger interceptor lines that transport flow from the local systems to the West Point Wastewater Treatment Plant.

The City of Seattle operates two CSOs in the LDW: #116 at South Brighton Street and #111 at Diagonal Way South. CSO #111 consists of eight separate overflow points discharging to a single outfall. The City also operates three EOFs in the LDW. The City of Seattle began monitoring the frequency and volume of discharges from its CSOs in 1999. CSO #116 has not overflowed since 1999. Over a 6-year period of record (1999 to 2005), the total annual discharge volume from CSO #111 has ranged from 0.6 to 74 million gallons. In 2005, Seattle Public Utilities modified the overflow structure on CSO #111's largest overflow point (#111 D) to allow more water to enter the King County treatment system and release less water to the LDW (Seattle Public Utilities 2008). In 2008, no overflow events were recorded from CSO #111; in 2009, five events, releasing a total of 2.1 million gallons, were recorded (Tetra Tech 2010b).

King County also operates nine CSOs and two EOFs that discharge to the LDW. For the period from 1999 to 2005, one of these CSOs had no recorded overflows. For the remaining eight CSOs discharging to the LDW, the average total monthly overflow volumes ranged from 0.12 million gallons (July) to 14 million gallons (November). King County has no record of an overflow event ever occurring at the pump station EOF located at the E. Marginal Way S outfall. The Duwamish East CSO/EOF also functions as an emergency bypass for a pump station; this CSO/EOF has not experienced an emergency overflow since 1989 (Nairn 2007). This location also contains an EOF for the siphon that traverses the LDW. This EOF had one overflow in 2005 and one in 2007 (King County 2010c).

Historically, direct sanitary sewer discharges were reduced as King County eliminated raw sewage outfalls and redirected wastewater to the West Point Wastewater Treatment Plant. Many industrial discharges were also rerouted from the LDW to the West Point Wastewater Treatment Plant. King County also developed industrial waste pretreatment and CSO reduction programs in accordance with the Clean Water Act. Since 1969, those programs have reduced contaminant discharges to the sewers and reduced CSO discharges of contaminants to the LDW.

Infrastructure improvements have greatly improved system storage capacity and reduced the number of discharges from the combined sewer systems (those that may include contributions of stormwater, sewage, and industrial waste streams). These combined systems are still in operation in some areas adjacent to the LDW, but their existence is very limited (Windward 2010). Continuing efforts to increase infiltration and treatment of stormwater and to educate businesses and residents are all designed to reduce pollutants entering the LDW. However, regional development and population growth may increase source loads of PAHs and other COCs (Ecology 2005).

Surface Water Runoff or Sheet Flow

Surface runoff is a potentially complete pathway for transport of COCs to the LDW. In areas adjacent to the LDW and lacking collection systems, contaminated soils or contaminants improperly stored either as raw or as waste materials could be carried directly over impervious surfaces (surface runoff) or through creeks and ditches to the LDW. For properties not adjacent to the shoreline, sheet flow generally enters a publicly-owned conveyance before discharging to the LDW.

Spills and/or Leaks to the Ground, Surface Water, or Directly into the LDW

Infrastructure and activities over or near the LDW have the potential to release COCs to adjacent sediments. Overwater activities occur on shoreline structures such as piers, wharves, and dolphins (discussed in Section 2.6.3). Historical industrial practices included dumping and sweeping waste from piers and through floor hatches in overwater buildings into the LDW. These practices have resulted in accumulation of contaminants in sediments near these structures. These practices are no longer common because BMPs are now required under environmental regulations. Contaminants in soils, surface water, or groundwater that resulted from spills or leaks at the properties adjacent to the LDW may reach the LDW.

Groundwater Migration/Discharge

Groundwater migration/discharge is a potentially complete pathway for transport of COCs to the LDW. Contaminated groundwater has been documented at several properties in the LDW drainage basin where groundwater flows toward the LDW. Seep and porewater sampling conducted in 2004 for the RI identified 82 seep locations throughout the LDW; 18 of these locations were selected for chemical analyses. The results of this study were discussed in the RI (Windward 2010). EPA and Ecology may further evaluate seeps as part of their continuing upland site cleanup and source control efforts.

Determining whether a contaminant identified in groundwater will reach sediment and surface water in the LDW is a complex process. The potential for groundwater transport to be a significant pathway at some locations will be assessed as part of facility-specific remedial investigations implemented under the 2004 source control strategy (Ecology 2004). For example, at the Boeing Isaacson/Thompson properties (RM 3.8), where high concentrations of arsenic were detected both in groundwater and in the sediments immediately offshore, the groundwater-to-sediment pathway will be investigated as part of the remedial investigation for that facility.

As part of the Phase 1 RI completed in 2003, a preliminary pathway assessment, based on the information available at the time for 12 upland facilities, was conducted to evaluate the potential for groundwater contamination to reach the LDW and contaminate sediment. Groundwater information through 2002 was summarized for the 12 upland facilities[17] identified by EPA and Ecology as preliminary facilities of interest for the RI. The Final RI,[18] completed in 2010, expanded the list to 45 facilities, adding shoreline properties associated with one of the 11 source control areas (SCAs) discussed in Appendix I of the RI[19] and those identified by Ecology as being facilities of interest for groundwater. The RI provided updated information on contaminants found in groundwater at 28 of the facilities for which groundwater data were available as of 2008. Groundwater data collected at these facilities were compared to contaminant concentrations in receiving sediments, but the potential for groundwater contaminants to affect LDW sediments was not assessed further in the RI. The following results were noted:

- At 7 of the 12 facilities evaluated in the 2003 preliminary assessment, evidence was found for metals accumulation in sediment to concentrations greater than SMS criteria or DMMP guidelines in potential groundwater discharge zones. The RI lists 20 facilities with detected metals in groundwater, and at 9 of these facilities one or more of these metals were also detected in nearby sediments at concentrations above the SQS.
- PCBs were not identified as a COC in groundwater in the 2003 preliminary assessment based on groundwater data available at the time and the known high retardation factors for PCB transport in groundwater. However, more recent data summarized in the RI have revealed detectable concentrations of PCBs in groundwater under eight facilities (Terminal 106, Duwamish Marine Center, Boeing Plant 2, PACCAR, Georgetown Steam Plant, North Boeing Field, Terminal 117, and Industrial Container Services). PCBs were detected in nearby sediments at all of these facilities.

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[17] The 12 facilities are Advance Electroplating (RM 4.1), Boeing Developmental Center (RM 4.8), Boeing Isaacson (RM 3.8), Boeing Plant 2 (RM 3.6), Great Western International (RM 2.4), Long Painting (RM 3.1), Terminal 117 (RM 3.7), PACCAR (former Kenworth Truck, RM 4.0), Philip Services/Burlington Environmental (RM 1.4), former Rhône-Poulenc (RM 4.2), South Park Landfill (RM 2.6), and Terminal 108 (RM 0.7). EPA is also evaluating groundwater from the Boeing Electronics Manufacturing Facility (EMF; upland site near RM 3.4). It was evaluated in the RI in the context of the Boeing Plant 2/Jorgensen Forge EAA SCA because groundwater from the EMF flows under these properties.

[18] In this FS, the Final RI (Windward 2010) is simply referred to as the RI.

[19] In 2002, only 11 source control areas were identified. By 2010, Ecology and the Source Control Work Group had identified 24 separate source control areas based on the extent of municipal storm and sanitary drain infrastructure.

- Elevated concentrations of PAHs were not detected in the groundwater or adjacent sediments at any of the 12 facilities in the 2003 assessment. Additional data included in the RI indicate detected concentrations of PAHs in groundwater at 9 facilities along the LDW, and at 6 of these facilities, PAHs were found above the SQS in nearby sediments.
- Volatile organic compounds (VOCs) were detected in groundwater at 18 facilities, including Great Western International (RM 2.3 to 2.4E), where chlorinated ethenes were detected in porewater and seeps. This facility is documented as having elevated VOCs in groundwater, but fate and transport analyses for VOCs indicated extensive degradation prior to discharge to the LDW (Windward 2010). Boeing Plant 2/Jorgensen Forge (and Boeing Electronics Manufacturing Facility [EMF]) also had elevated concentrations of VOCs in groundwater, and VOCs were also detected in seeps and sediments.

All of these assessments are preliminary. The source control program will prepare more detailed, facility-specific assessments of the potential for groundwater contaminants to contribute to sediment contamination.

Bank Erosion/Leaching

Unprotected shoreline banks are susceptible to erosion by wind, surface water, and surface runoff, creating a pathway for contaminated soils to reach LDW surface sediments. Shoreline armoring and vegetation may reduce the potential for bank erosion. Currently, the majority of the LDW shoreline is armored with constructed steel and concrete bulkheads, sheet-pile walls, and riprap banks, limiting bank erosion in many areas. Bank erosion is more likely to occur in unarmored areas such as the banks of Kellogg Island, the shoreline east of the island, and areas to the south near the Upper Turning Basin.

Much of the material behind the riprap, seawalls, and other armoring is fill, placed during industrial/commercial development of the LDW. Historically, the source and quality of fill materials was not tracked, which leads to potential source control issues in these areas based on the lack of knowledge about their nature (i.e., historical contamination). Unknown contaminant concentrations in historical fill materials may be related to potential pathways such as erosion, groundwater/tidal communication to the LDW, and infiltration to storm drains or other discharge infrastructure.

Shoreline structures and conditions are discussed in more detail in Section 2.6.4. However, because of the limited amount of data available for the banks, this pathway was not evaluated in the FS from a contamination perspective. It is discussed only in reference to the physical conditions of the banks (i.e., whether they may be erodible, but not whether the bank soils are contaminated). Both the physical conditions and potential contamination of the banks will be important on a case-by-case basis at the remedial design level and will be addressed as part of location-specific cleanups and through ongoing source control efforts.

Atmospheric Deposition

Atmospheric deposition allows air pollutants to enter the LDW directly, and to reach the LDW via stormwater from the watershed. Air pollutants may be transported over long distances by wind, and can be deposited on land and water surfaces by precipitation or particle deposition. Global atmospheric transport of PCBs from parts of the world where they are still used represents an ongoing pathway. Additional information on recent and ongoing atmospheric deposition studies in the LDW area is summarized in the LDW Source Control Status Reports (Ecology 2007c, 2008a, 2008b, 2009, and subsequent updates). Ecology will continue to monitor these efforts.

Air pollutants may be generated from direct or indirect sources. Direct sources include industrial smokestacks and activities such as painting, sandblasting, loading/unloading of raw materials, and other activities. Indirect sources include dispersed sources such as vehicle emissions, aircraft exhaust, resuspension of particulates, and off-gassing and degradation of common materials such as plastics and building materials.

Section 9 of the RI (Windward 2010) reported (based on Puget Sound Clean Air Agency records) that over 200 businesses in the Duwamish Valley (the airshed of the LDW[20]) are registered as active sources of air pollution. Motor vehicle traffic on Interstate 5, State Routes 99 and 509, and local roads also produces nitrous oxide, black carbon (i.e., soot), and other emissions through the burning of fossil fuels.

Atmospheric releases of PCBs have been significantly minimized by the United States ban on production of PCBs in 1979. However, PCBs contained within old paints, caulks, and other building materials remain in the watershed, and thus represent ongoing sources, with releases from these media via off-gassing (to the atmospheric deposition pathway) and physical degradation (transported via stormwater discharge and runoff pathways).

Transport of Resuspended Contaminated Sediments

Sediments in one part of the LDW that are scoured and transported can contaminate sediments in other parts of the LDW, including remediated areas. The STM (QEA 2008) delineates areas where sedimentation is predicted to bury historically impacted

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[20] The Duwamish Valley (bounded to the west by West Seattle and to the east by Beacon Hill) is smaller than the LDW drainage basin. The combined sewer and storm drainage systems, discharging to the LDW, extend beyond the Duwamish Valley. For example, the Duwamish/Diagonal CSO/SD basin extends north and east into the International/Central District and Beacon Hill neighborhoods of Seattle.

sediment. However, in scour areas or areas disturbed by mechanical actions, contaminated subsurface sediments may become exposed, and either surface or previously subsurface sediments may be transported. Section 2.3.1.1 discussed both high-flow and ship-induced scour.

Additionally, migration from upstream sources to the LDW continues via inflow of suspended sediments and surface water that contain contaminants.

2.4 Source Control Strategy

The LDW source control strategy (Ecology 2004) describes the process for identifying source control issues and implementing effective source controls for the LDW. The strategy is used to identify and manage sources of potential contamination and recontamination in coordination with sediment cleanups. The goal is to limit sediment recontamination that exceeds LDW sediment cleanup goals. Existing administrative and legal authorities will be used to perform inspections and required source control actions.

The LDW source control strategy (Ecology 2004) focuses on controlling contamination that affects LDW sediments. It is based on the principles of source control for sediment sites described in *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002b) and Washington's SMS. The first principle is to control sources early, starting with identifying all ongoing sources of contaminants to the site. It is anticipated that the Record of Decision (ROD) will require that sources of sediment contamination to the LDW be evaluated, investigated, and controlled as necessary. Dividing source control work into specific Source Control Action Plans (SCAPs) and prioritizing actions within those plans to coordinate with sediment cleanups will address the guidance and regulations and will be consistent with the remedial alternatives in this FS.

Ecology is the lead agency for implementing source controls in the LDW and works in cooperation with local jurisdictions and EPA to create and implement source control strategy and action plans and to prioritize upland cleanup efforts in the LDW. In 2002, these entities formed the LDW Source Control Work Group (SCWG), which conducts several different source control activities within the LDW area. Primary members of the group include EPA, Seattle Public Utilities, King County, and the Port of Seattle. The LDW source control strategy (Ecology 2004) also identifies various regulatory programs at EPA and Ecology that are called upon as needed for source control as well as several ad hoc members of the SCWG, including the City of Tukwila, Puget Sound Clean Air Agency, and Washington State Departments of Transportation and Health. All LDW SCWG members are public entities with various source control responsibilities and the collective purpose is to share information, identify issues, develop action plans for source control tasks, coordinate implementation of various source control measures, and share progress reports on these activities.

The LDW source control strategy describes how recontamination of LDW sediments will be controlled to the maximum extent practicable. The goal is to limit sediment recontamination that exceeds site-specific standards, where feasible. The LDW source control efforts are designed to identify and manage sources of contaminants to waterway sediments in coordination with sediment cleanups. This strategy provides the framework and process for identifying source control issues and implementing practical control of contaminant sources. The strategy also serves three other primary functions. First, it sets up the reporting process for tracking and documenting all of the source control work performed throughout the LDW source area. This information is necessary for EPA's administrative records and remedial decisions. Second, the strategy broadly prioritizes source control work according to the schedules proposed for sediment cleanups (e.g., EAAs, other areas to be identified in the ROD). These priorities or "tiers" for source control efforts are listed below. Finally, the strategy identifies the basic steps for performing source control: 1) identify, 2) characterize, and 3) control sources and pathways of contamination to the LDW.

The success of the strategy depends on the coordination and cooperation of all public agencies with responsibility for source control in the LDW area, as well as prompt compliance by businesses that must make the necessary changes to control releases from their properties. The strategy is being implemented through the development of a series of detailed SCAPs that will be coordinated with sediment cleanups, beginning with the EAAs. The SCAP for each source control area describes potential sources of sediment contaminants and the actions needed to control them. Each SCAP evaluates whether ongoing sources are present that could recontaminate sediments after cleanup. In addition, the SCAPs describe source control actions that are planned or currently underway, including sampling and monitoring activities to identify additional sources. The tiers are defined as follows:

- **Tier One –** Source control work associated with EAAs[21]
- **Tier Two –** Source control work associated with sediment cleanup areas identified for final or long-term cleanup through the RI process or in the LDW decision document
- **Tier Three –** Source control work associated with drainage basins discharging to LDW sediments that have not been identified for Tier One or Tier Two source control activities through the RI/FS process

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[21] The Tier 1 areas published in the Phase 1 RI (Windward 2003a) included two areas that were not carried forward as EAAs because remedial actions for sediments are not scheduled to begin before the issuance of the LDW ROD. Five of the Tier 1 areas are currently EAAs. The other two areas are included in the Tier 2 areas.

- **Tier Four –** Source control work associated with sediment areas that are remediated and become subsequently recontaminated above SMS criteria or LDW cleanup goals based on post-cleanup monitoring.

Since 2002, the SCWG has identified 24 SCAs, which are generally based on stormwater and CSO infrastructure and drainage to the LDW study area (Figure 2-22). These 24 SCAs are based on drainage to ensure that source control will be conducted for the whole LDW, not just the areas identified for sediment cleanup. Ecology develops SCAPs for each SCA that describe potential sources of contamination that may affect sediments. They also describe source control actions that are planned or underway, and sampling and monitoring that must be done. The source control actions are subdivided into high, medium, and low priority tasks. Ecology and the other agencies identify those responsible for contamination and work with them and relevant SCWG partners to control contamination.

Ecology continues to develop SCAPs for the LDW. The first step in developing a SCAP is to summarize existing information and find out what is missing (data gaps). As of July 2011, Ecology had published SCAPs for 18 of the 24 SCAs. Ecology is currently working with its consultants to develop data gap reports and SCAPs for the remaining SCAs. Many source control documents are available on Ecology's LDW Source Control webpages, which launch from the Toxics Control Program tab on Ecology's home page at http://www.ecy.wa.gov. King County, the City of Seattle, and the Port of Seattle also have web content about their respective roles and work in LDW source control.

The status of the source control efforts within the LDW drainage basin as of September 2010 is described below (Ecology 2011b). Facilities named below are displayed on Figure 2-22:

- One hundred ninety-six confirmed or suspected contaminated upland facilities within the LDW drainage basin have been identified.
- Thirteen facilities along or near the LDW are under agreed orders in Ecology's cleanup process (MTCA). The facilities are:
    - Jorgensen Forge (uplands)
    - North Boeing Field/Georgetown Steam Plant
    - 8801 East Marginal Way (former Kenworth Truck)
    - South Park Landfill
    - Fox Avenue Cleanup
    - Glacier Northwest, Inc./Reichhold
    - Crowley Marine Services

  - Duwamish Shipyard
  - Industrial Containers/Trotsky/NW Cooperage
  - Douglas Management Properties
  - Boeing Isaacson-Thompson
  - Port of Seattle Terminal 115 North
  - Duwamish Marine Center.

- Ecology conducted site investigations at:
  - South Park Marina (formerly A&B Barrel)
  - Basin Oil
  - Industrial Container Services (formerly Northwest Cooperage)
  - Douglas Management Company/Alaska Marine Lines
  - Washington Liquor Control Board Warehouse.

- Four voluntary cleanups under MTCA are occurring at the following facilities along or near the LDW:
  - Port of Seattle Terminals 106/108
  - Boeing Developmental Center uplands and sediments (Section 2.7.2)
  - General Services Administration – Federal Center South
  - City of Seattle 7th Avenue Pump Station.

- Five additional facilities in the LDW SCAs are under agreed orders administered by Ecology's Hazardous Waste Treatment and Reduction (HWTR) program:
  - Art Brass Plating
  - Blaser Die Casting
  - Capital Industries
  - General Electric-Dawson Street Plant
  - Philip Services Georgetown.

- Nine facilities along or near the LDW are under an EPA cleanup process. These facilities are:
  - Boeing Plant 2 (Resource Conservation and Recovery Act [RCRA] corrective action)

  - ▸ Jorgensen Forge shoreline (Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA] removal action)
  - ▸ Stormwater outfall along Boeing Plant 2/Jorgensen property line (CERCLA removal action)
  - ▸ Rhône-Poulenc/Monsanto (RCRA corrective action)
  - ▸ Port of Seattle Terminal 117 (CERCLA removal action)
  - ▸ Slip 4 (CERCLA removal action)
  - ▸ Boeing EMF (CERCLA removal action)
  - ▸ North Boeing Field/King County International Airport Storm Drain Treatment System (CERCLA removal action)
  - ▸ Tully's/Rainier Commons (Toxic Substance Control Act).

- ♦ From 2003 to 2005, the City of Seattle and King County conducted a joint business inspection program in the Diagonal Ave S CSO/SD area to evaluate stormwater, industrial wastewater, spill containment, and hazardous waste management practices at each property and to bring businesses in compliance with local code requirements. During that time, 1,100 inspections were completed at approximately 625 businesses. The City took over the business inspection program in 2006, and King County continued to inspect the businesses in the LDW that are permitted under its Industrial Waste Program. King County also provides technical assistance to Seattle Public Utilities (SPU) as needed on issues related to industrial waste and hazardous waste. In 2010, the City completed the first round of inspections at the approximately 1,275 high-risk pollutant generating sites in the LDW drainage basin. Between 2003 and September 2011, approximately 2,900 inspections were completed at businesses throughout the LDW drainage basin. The LDWG partners have also collected sediment samples from storm drains and combined sewer systems to help identify and characterize sources discharging to the storm and combined sewer[22] collection systems in the LDW. As of June 2011, over 1,000 samples had been collected, mostly by SPU.

- ♦ Approximately 500 combined hazardous waste and water quality inspections have been completed under the Ecology LDW Urban Waters Initiative (March 2007 through July 2010). From October 2009 through September 2010, water quality inspections numbered 66. Of these, 33

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[22] King County has also collected CSO water samples in the Duwamish River Basin.

notices of violation have been issued, 4 administrative orders have been issued, and 4 penalties have been assessed.

- Approximately 105 facilities in the LDW drainage basin have Ecology water quality discharge permits (NPDES); approximately 90 facilities are regulated under a general industrial stormwater permit; 2 active facilities have individual industrial stormwater permits; 2 facilities operate under general discharge permits for boatyards; and 4 facilities operate under general discharge permits for sand and gravel facilities.
- Four local governments have municipal stormwater general discharge permits (Phase I for the City of Seattle and King County, secondary permittee under Phase I for the Port of Seattle, and Phase II for the City of Tukwila).
- Two local governments (the City of Seattle and King County) have individual discharge permits for their CSO/SD systems.
- Several MTCA agreed orders have been issued by Ecology to evaluate upland properties in the LDW watershed (Figure 2-22).

Source control is an iterative process. Early steps are often revisited and conclusions refined by information gathered later. Source identification in one basin may influence source control investigations in another basin. Addressing each potential source may involve one or more of the following elements: source control investigations, upland site assessment and cleanup, inspections, source tracing, sampling, and monitoring.

In conjunction with source control activities led by Ecology, the City of Seattle is conducting a source-tracing study and has collected storm drain sediment samples (from catch basins and within storm drain systems) within areas of the LDW drainage basin.[23] The City of Seattle compiled data from storm drain sediment samples collected by Seattle Public Utilities, King County, and The Boeing Company for use in this FS as part of the modeling efforts described in Section 5 and in Appendix C, Part 3. PCBs were detected in 84% of 953 samples. Through this source tracing exercise, PCBs have also been found in various building materials (e.g., paint, caulk, and other sealants). Unlike other contaminants, PCBs exhibited a distinct geographic distribution, with hotspots identified at Terminal 117, Rainier Commons, North Boeing Field/ Georgetown Steam Plant, and Boeing Plant 2/Jorgensen Forge. The latter two have been sampled extensively and make up a significant portion of the overall source-tracing dataset. Other activities conducted by municipalities and property operators

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[23] Other parties, such as The Boeing Company and the Port of Seattle, have also been collecting source-tracing samples at their sites.

include inspections, NPDES-required stormwater discharge sampling, development of stormwater pollution prevention plans and source control strategy plans, use of BMPs, and other activities.

Arsenic was detected in 52% of 576 sediment samples collected from within storm drain systems that discharge to the LDW. Arsenic concentrations were fairly uniform and relatively low, with only 5 percent of the samples exceeding the SQS (57 mg/kg dw) and only 3 percent exceeding the CSL (93 mg/kg dw). Samples containing elevated arsenic concentrations were not clustered in any particular geographic area.

cPAHs were detected in 93% of 543 storm drain sediment samples. Concentrations did not display a distinct geographic distribution. cPAHs were present at concentrations exceeding 25,000 µg TEQ/kg dw (used as a screening level) at various locations throughout the drainage basin, typically in on-site drainage structures (catch basins and oil/water separators) at facilities engaged in transportation-related activities (e.g., bus and airport operations), maintenance facilities, service stations, foundries, and fast food facilities.

In 2004 and 2005, dioxins/furans were analyzed in nine storm drain sediment samples in catch basins and maintenance holes, one storm drain sediment sample upstream of an oil-water separator, and one street dirt sample. Concentrations ranged from 6.2 to 26 ng TEQ/kg dw in the storm drain sediment samples and 91 ng TEQ/kg dw in the street dirt sample (Integral 2008). The median value for all samples was 18 ng TEQ/kg dw. Appendix C and Section 5 present summary statistics for storm drain and CSO data collected within the LDW basin and used in the chemical modeling.

2.5 Key Observations and Findings from the RI

Key findings from the RI (Windward 2010) are summarized below.

- Over the past 100 years, the LDW has been highly modified from its natural configuration to support urban and industrial development. Changes have included reductions in and control of water flow, significant shoreline modifications, loss of intertidal habitat, and installation of riprap, pier aprons, and sheet pile walls. Some limited areas of natural shoreline still exist within the LDW.

- Industrial and commercial facilities occupy most of the shoreline; one residential community (South Park) is also located along the shoreline, and another community (Georgetown) is nearby.

- The LDW is currently used as an industrial navigational corridor. It also supports recreational uses such as boating, kayaking, fishing, and beach play. The LDW is also part of Tribal Usual and Accustomed fishing areas.

It is also one of the locations of the Muckleshoot Tribe's commercial, ceremonial, and subsistence fishery for salmon, and the Suquamish Tribe actively manages aquatic resources north of the Spokane Street Bridge, located just north of the LDW study area. The Duwamish Tribe uses Herring's House Park and other parks along the Duwamish for cultural gatherings.

- Despite significant alterations in habitat and areas with elevated COC concentrations, the LDW contains a diverse assemblage of aquatic and wildlife species and a robust food web that includes top predators.
- The majority of high arsenic and total PCB concentrations in surface sediment are located within fairly well-defined areas. The locations of the highest arsenic and total PCB concentrations are generally not in the same areas, indicating that sources likely differ for these two contaminants. Areas with the highest cPAH concentrations are located in many of the same areas identified for arsenic and total PCBs, but are also more dispersed. Several areas have high dioxin/furan concentrations in surface sediments.
- Sediment is continually depositing within the LDW, with almost all new sediment (99%) originating from the Green/Duwamish River system. The STM (QEA 2008) estimates that over 200,000 metric tons of sediment per year enter the LDW. Approximately 50% of this total deposits in the LDW. STM modeling runs indicate that approximately 90% of the total bed area in the LDW receives 10 cm of new sediment (from the combined Green/Duwamish River and lateral sources) within 10 years or less. This sediment is mixed with the existing surface sediment through various processes, including bioturbation and propeller wash.
- A few areas in the LDW will be scoured during high-flow events. Based on the STM, the maximum scour depth is relatively shallow, and is generally limited to sediment in the top 20 cm; thus, deeper sediment would not be exposed as a result of high-flow events. Scour to these relatively shallow depths is estimated to occur in relatively small areas of the LDW. The STM did not account for scour from localized activities, such as discharges from outfalls, tugboat maneuvering, or anchor dragging, which could have caused localized erosional environments. Routine boat traffic is expected to mix the top few cm of sediment, which is part of the biologically active zone also mixed by benthic invertebrates, whereas tugboat maneuvering is a potential source of localized erosion that could disturb sediment at greater depths in small areas. In addition, in some areas, ships may have caused localized erosion from physical forces (e.g., anchor dragging)

unrelated to propeller-driven scour. Location-specific information, in addition to the STM results, will be evaluated in any future remedial design.

- The physical CSM of net depositional environments is supported by both physical and chemical lines of evidence, including lithology and chemistry profiles in sediment cores. The depths of most (70%) peak PCB concentrations were consistent with the estimated sediment deposition rates, with a few exceptions.
- Based on the STM and with ongoing source control in the LDW basin, LDW surface sediment is generally expected to become more similar in character over time to the sediment being transported by the Green/Duwamish River system; localized areas may continue to be influenced by inputs from sources in the LDW basin.

2.6 Additional Considerations for the FS

Data presented in the RI (Windward 2010) are expanded upon in this section for the purposes of this FS. This section also discusses information not presented in the RI that may be relevant to selecting remedial technologies and developing remedial alternatives.

2.6.1 Sediment Physical Properties

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

- Dredgeability or “digability”
- Production rates
- Sediment handling
- Sediment dewatering
- Slope stability
- Bearing capacity for cap placement.

Grain size composition, total organic carbon (TOC), other geotechnical properties such as porosity and bulk density, and the presence of debris were evaluated to provide evidence of the manner in which sediment will behave when handled during remediation. In addition, TOC is determined so that dry weight concentrations of non-polar organic compounds can be organic carbon-normalized for direct comparison to the SMS criteria. TOC also affects the bioavailability of contaminants.

2.6.1.1 Grain Size Composition and Total Organic Carbon

Sediment composition varies throughout the LDW, ranging from sand to mud (fine-grained silt and clays) with varying amounts of organic material, depending on the source of the sediments and the local current velocity. Silt and organic silt are the dominant sediment types, based on Atterberg limits tests, in much of the LDW main channel and in the slips. A mixture of silt and sand dominates the subsurface sediment upstream of the Upper Turning Basin and downstream of Kellogg Island. Sand is predominant from RM 1.1 to 1.8 (mostly west of the navigation channel, but also within it from RM 1.1 to 1.5), on the western side of the navigation channel from RM 2.2 to 2.5, and across the LDW from RM 3.2 to 3.4. The sediment type in the upper 4 ft presented in Figure 2-23 is based on an interpretation from 59 cores collected for the RI in 2006. There is some uncertainty associated with spatially interpolating the extent of physical characteristics between these cores.

Surface sediment toward the mouth of the LDW and on mudflats consists predominantly of fine-grained silts. Overall, the fines (silt [3 to 6.25 micrometers (µm)]+clay [<3 µm]) content of surface sediment in the LDW has been reported to be highly variable, with an average content of 53%. Surface sediment in the navigation channel has a higher fines content than other sediment. The average fines content in the navigation channel was 62%; the 10th and 90th percentile fines contents were 29 and 82%, respectively. Fines content was more variable outside of the navigation channel (excluding the slips), with 10th and 90th percentile contents generally ranging from about 13 to 87%, respectively, and an average content of 53%. Average fines contents have been calculated using point-based averages. Figure 2-24 displays an interpolation of the surface sediment fines content.

Three of the five slips along the LDW had high fines contents relative to the overall LDW average. Slips 1, 3, and 6 had average fines contents of 79, 71, and 87%, respectively. The fines contents of Slips 2 and 4 were lower, with average values of 41% and 57%, respectively. The area upstream of RM 5.0 had a much lower average fines content (approximately 11.5%).

Fines content in the upper 4 ft of the subsurface sediment ranges from 2% to 97%, with a mean of 54% in the 56 RI cores.

TOC content in surface sediment does not vary widely throughout the LDW, and has an average value of 1.9% (Figure 2-25). Outside the navigation channel, the 10th and 90th percentiles were 0.80 and 2.9%, respectively. The TOC content in the navigation channel was less variable than the TOC content outside the navigation channel, with 10th and 90th percentiles of 1.2 and 2.6%, respectively. The average TOC content (1.9%) was the same within and outside the navigation channel. The TOC content in Slips 1, 3, 4, and 6 was slightly higher than the LDW-wide average, with average TOC contents of 2.3, 2.2, 2.6, and 2.7%, respectively. In Slip 2, the average TOC content (1.5%) was lower than the LDW-wide average. Average TOC content was calculated using point-based averages. The area upstream of RM 5.0 had a lower average TOC content (0.84%).

2.6.1.2 Other Geotechnical Characteristics

To understand the engineering properties of sediment that could be the subject of remediation, geotechnical parameters were determined for the upper 4 ft of a subset of sediment cores collected in 2006. These parameters included grain size distribution, moisture content, specific gravity, Atterberg limits (i.e., liquid limit, plastic limit, plastic index), bulk density (dry and wet), and porosity.

Analysis of the grain size distributions of the sediment cores indicated that the median grain size (D_{50}) in the upper 4 ft ranged from 6 µm (or 0.006 millimeter [mm]) to 520 µm (0.52 mm).[24] This grain size range is classified as fine silt to medium sand. Sediment grain size was generally finer in the navigation channel, and coarser in the higher, intertidal zones. In the channel, the D_{50} in the upper 4 ft ranged from 6 µm (0.006 mm) to 320 µm (0.32 mm), which is fine silt to fine sand. In the subtidal bench areas, the D_{50} in the upper 4 ft ranged from 9 µm (0.009 mm) to 410 µm (0.41 mm). In the intertidal areas, the D_{50} in the upper 4 ft ranged from 10 µm (0.01 mm) to 520 µm (0.52 mm). The D_{50} did not vary substantially with depth in the channel and subtidal bench areas. In the intertidal area cores, however, the average of the D_{50} values in the upper 2 ft was 150 µm (0.15 mm), while the average D_{50} values in the lower (2 to 4 ft) sample intervals was closer to 260 µm (0.26 mm).

Sample results for specific gravity, porosity, and wet density did not vary notably with depth, indicating that sediment texture in the upper 4 ft is relatively uniform. The mean particle density of all subsurface sediment samples across similar core intervals ranged from 2.64 grams per cubic centimeter (g/cm^3) to 2.66 g/cm^3. The mean sediment porosity ranged from 59% to 64%, and the mean wet bulk density ranged from 102 pounds per cubic foot (lb/ft^3) to 104.4 lb/ft^3.

Other geotechnical properties varied with depth:

- The mean moisture content of all samples was 75% dw at the surface, decreasing to 63% dw below the 2-ft interval, consistent with the decrease in water content with depth as noted on the core logs.

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[24] The D_{50} in the top 4 ft of the sediment is an important consideration when evaluating remedial technologies, such as soil washing.

- The mean dry bulk density across similar core intervals increased with depth from 60.4 lb/ft^3 to 67.2 lb/ft^3, again, consistent with the decrease in water content (Windward and RETEC 2007).
- Atterberg limits tests were performed on fine-grained sediments and revealed that the mean liquid limit of all subsurface sediment samples ranged from 61.2% dw to 70.7% dw, and the mean plastic limit ranged from 35.0% dw to 39.3% dw. Subsurface sediment samples exhibited medium to high plasticity, with the mean plasticity index varying from 26.2% dw to 32.5% dw, consistent with most of the core logs with noted organic compressible texture (Windward and RETEC 2007).

Other geotechnical information is available from past studies that evaluated the engineering feasibility of construction projects in and around the LDW. Table 2-7 lists studies conducted around the LDW for which in-water cores (or upland cores used in cross sections discussed in Section 6) were collected.

2.6.1.3 Debris

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

It is not feasible to characterize and quantify the type and extent of all the debris that will be encountered during dredging until dredging is under way; however, design-level assessment may include side-scan sonar, magnetometer, and diver surveys to assist in qualitatively assessing buried debris. Debris sweeps are assumed to be a part of the dredging activities for all remedial alternatives (see Section 8).

Scattered wood and anthropogenic debris (e.g., glass shards, sand blast grit) were identified in 34 of the 56 cores collected for the RI. Six cores (SC17, SC28, SC40, SC47, SC50, and SC54) were sampled with the vibracorer because the MudMole™ sampler (which was the sampling device used for the other cores) was not able to penetrate layers of sand or gravel to depths of 10 ft below the mudline.

The cores with more than 50% visually identified anthropogenic material or debris by volume included SC2 (rock flour), SC26 (gravel), SC28 (sand blast grit), and SC38 (wood and sheen). Trace to moderate hydrocarbon-like sheens were also observed in several cores at depth. Table 2-8 and Figure 2-23 summarize these findings.

2.6.2 Dredging and Capping Events

Historical dredging and capping events were evaluated in the FS for a number of reasons:

- Material accumulated after dredging events can provide evidence of sedimentation rates, sediment transport, and characteristics of sediment contributed from upstream sources (when an area at the upstream end of the LDW, such as Delta Marine, is repeatedly dredged).
- Project dredging depths in both the navigation channel and berthing areas provide information regarding the operational depths necessary for safe vessel navigation. These required depths are important to understand when considering capping remedies.
- Historical dredging records often describe equipment that has been used successfully within the LDW.
- Historical dredging activities often describe material types and quantities that have been removed from the LDW.
- Monitoring conducted at capping sites provides useful data to evaluate the long-term viability of capping in the LDW and recontamination potential.

The dredging projects conducted to maintain navigable depths and the contaminated sediment projects discussed below are valuable case studies that provide information regarding successful dredging and capping methodologies employed in the LDW. Relevant projects are reviewed in greater detail in Section 7 to assist in evaluating remedial technologies.

2.6.2.1 Navigation Channel

An understanding of the dredging that has occurred in the navigation channel is important for the FS because it describes the quantity and nature of sediment originating from the upstream Green/Duwamish River system. Contaminant data associated with the dredging events characterize the quality of these sediments. Because the LDW is a navigational waterway, numerous dredging events have occurred to maintain appropriate depths. These events generally began in the early 1900s when the Lower Duwamish River was straightened into a navigation channel. Most navigation channel dredging since the 1950s has occurred in the upstream portions of the LDW above RM 3.3.

Today, the USACE is responsible for maintaining the navigation channel to the following authorized depths and widths (see Figure 2-26):

- -30 ft MLLW and 200 ft wide from Harbor Island (RM 0.0) to the First Avenue South Bridge (RM 2.0), also known as the Harbor Island and Georgetown Reaches
- -20 ft MLLW and 150 ft wide from the First Avenue South Bridge (RM 2.0) to Slip 4 (RM 2.8), also known as the First Avenue South Reach
- -15 ft MLLW and 150 ft wide from Slip 4 (RM 2.8) to the Upper Turning Basin (RM 4.7), also known as the South Park and 14th Avenue Bridge Reaches. The authorized dimensions of the navigation channel portion of the Upper Turning Basin are 250 ft wide by 500 ft long (USACE 2006).

To maintain navigation depths, the USACE conducts dredging every one to three years in the upstream areas. The area typically dredged under this program is the Upper Turning Basin and downstream to approximately RM 4.0.

Without routine maintenance dredging of the LDW, shoaling would create a shallower channel and inhibit the safe passage of vessels. The Upper Turning Basin acts as a settling basin for sediments that would normally migrate downstream. Routine maintenance dredging keeps sediments from accumulating beyond the holding capacity of the basin. Without the current maintenance dredging, the sediment would continue to migrate downstream via bed load transport and settle in downstream areas. This shoaled material, generally consisting of fine- to medium-grained sand with some silt,[25] is currently dredged in the Upper Turning Basin before it migrates downstream, thereby minimizing the need for maintenance dredging in the lower portion of the LDW.

Table 2-9 summarizes recent maintenance dredging events in the LDW navigation channel between 1986 and 2010. Figure 2-27 shows the locations of the dredging events. The yearly volumes of sediment dredged from the LDW have varied widely, from a minimum of 34,000 cubic yards (cy) dredged in 1986 to a maximum of 200,000 cy in 1992. For the most recent event (February to March 2010), 60,371 cy was dredged from RM 4.18 to the Upper Turning Basin (USACE 2010a).

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[25] Figure 2-24 illustrates fine-grained material in the surface sediment of the navigation channel. Subsurface sediment in the navigation channel, particularly the Upper Turning Basin, is coarser and is primarily fine- to medium-grained sand, with some silt.

2.6.2.2 Dredging Events at Berthing Areas

Berthing areas are typically adjacent to piers, wharves, and dolphins where vessels are moored for temporary parking or unloading/loading. Berthing areas are important to consider in the FS because they represent areas where:

- Specific navigable depths must be maintained.
- Maneuvering vessels may cause scour.
- Remediation and data collection may be difficult because of the presence of moored vessels, overwater structures, or other physical obstructions.

Most berthing areas are within Reach 1 (RM 0 to 2.2). The 2002 Port Series No. 36 publication (USACE 2002), a periodic inventory of shipping facilities within all waters operated by the Port of Seattle, lists berthing areas in the LDW. Table 2-10 and Figure 2-28 summarize these berthing areas, which were generated based on this publication, communications with the Port of Seattle, historical dredging records, established tug routes, and field surveys.

Dredging occurs in these berthing areas to maintain depths for shipping and marina uses. The depths at which these areas are maintained also must be considered when developing remedial alternatives. Evidence of this dredging was obtained from Dredged Material Management Office memos, sampling and analysis plans, and, to a lesser extent, post-dredging confirmation reports. Table 2-11 summarizes the locations, dates, depths, volumes, and other details of private maintenance dredging events in the LDW since 1980. Most dredging in private berthing areas occurs in the downstream portions of the LDW below RM 3.0 because of the large vessels that transit that area. Private dredging has removed about 160,000 cy of material since 1980. Almost 72% of this material, based on reported volumes, was deemed acceptable for open water disposal, based on sediment quality testing. The LDW also has several berthing areas where dredging either has not occurred or has not been documented.

2.6.2.3 Contaminated Sediment Dredging and Capping with Clean Material

Several dredging and capping projects have been conducted in the LDW or made use of clean dredged materials from the LDW for the purpose of capping contaminated sediment. It is important to review these projects for the FS because they strongly relate to the evaluation of remedial technologies and alternatives for the LDW cleanup projects. Prior dredging conducted in the LDW for the purpose of sediment remediation can provide:

- Information regarding the chemical and physical characteristics of the removed sediments.

- Descriptions of equipment and remedial approaches that have been used within the LDW. These records provide information on a number of technical performance areas related to the removal of contaminated sediments, including dredge production rates, impacts of debris, sediment transportation and off-loading methods, sediment treatability and disposal methods, and environmental impacts.
- An understanding of the ability of a remedial operation to achieve cleanup goals and of the factors (e.g., debris, residuals) that may have an effect on that ability.

Sediment remediation projects completed in the LDW in the past 30 years are briefly described below and in Table 2-12.

- In September 1974, 260 gallons of Aroclor® 1242 where spilled into Slip 1. In October 1974, an emergency removal operation was undertaken by EPA, in which divers recovered approximately 70 to 90 gallons of the PCBs using hand-held pumps. This Phase 1 removal operation reduced the pre-dredging surficial Aroclor® 1242 concentration from greater than 30,000 mg/kg wet weight (ww) to about 1,500 mg/kg ww.[26] A subsequent Phase 2 remediation was undertaken by the USACE in March 1976 as the first major dredging operation in the United States to remove PCB-contaminated sediments. Prior to the Phase 2 dredging, the average surficial Aroclor® 1242 concentration was 4 mg/kg ww in the target area. A Pneuma dredge pump, deployed from the USACE vessel *Puget*, was used to remove sediment, resulting in a 10-ft-deep hole. The post-dredging surficial Aroclor® 1242 concentrations at the stations monitored ranged from 0.01 to 8 mg/kg ww (Blazevich et al. 1977).
- The first contained aquatic disposal (CAD) project in Puget Sound was conducted in 1984. In this project, 1,100 cy of PCB-contaminated sediments were dredged from a portion of the LDW navigation channel at RM 0.5, bottom-dumped into a CAD site in the West Waterway, and covered by 4,200 cy of clean sand dredged from the Upper Turning Basin (Battelle 2001, USACE 1994).
- Four sediment remediation projects were conducted in the LDW either as EAAs or before the AOC was signed (i.e., Norfolk CSO/SD, Boeing Developmental Center south storm drain area, Duwamish/Diagonal EAA), and Slip 4/EAA. Sediments were dredged and capped in these areas. These projects are described in more detail in Section 2.7.

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[26] Note that data from these reports are reported in wet weight.

Sediment remediation projects that utilized LDW sediment as capping material are summarized below:

- Beginning in 1984, sediments dredged from the upstream portions of the LDW for navigation maintenance have been used as capping material for several nearshore remediation projects in Elliott Bay and in the West Waterway (Battelle 2001). These projects used "clean" sands, generally from upstream portions of the LDW, for capping to cover and isolate *in situ* contaminated sediment or for CAD projects (Battelle 2001, USACE 1994).
- Between 1989 and 1994, four contaminated sediment capping projects were conducted along the Seattle waterfront, each with varying COCs and COC concentrations. These included the Pier 51 Ferry Terminal Expansion, Denny Way CSO, Pier 53-55 Sewer Outfall, and Pier 64/65 capping projects. The capping material for each project, ranging from about 10,000 cy (Pier 51) to about 22,000 cy (Pier 53-55), was obtained from LDW maintenance dredging (Battelle 2001).
- In 2004, approximately 67,000 cy of dredged material from the Upper Turning Basin was beneficially used as capping material to remediate the 58-acre Pacific Sound Resources (PSR) marine operable unit (located in Elliott Bay just outside of the West Waterway). PSR is the site of a former wood-treating facility. The sandier portion of the Upper Turning Basin material was used in nearshore areas where it met design specifications for grain size; finer material was used for deeper parts of the PSR cap.

2.6.3 Overwater and In-water Structures

The majority of upland areas adjacent to the LDW have been industrialized for many decades. Overwater and in-water structures, primarily in the form of wharves, piers, docks, utility crossings, dolphins, and piles are prevalent along the LDW to support industrial and commercial activities. Overwater structures occupy about 19,700 linear ft or 3.7 miles, representing about 24% of the total LDW shoreline (see Figures 2-28 and 2-29).

Existing overwater structures have been catalogued using the 2002 Port Series No. 36 publication (USACE 2002), the Duwamish Waterway Shoreline Inventory (Terralogic and Landau 2004), high-resolution ortho-rectified aerial photographs, oblique aerial photographs available at public internet sites (MSN live search), and field observations. Table 2-10 summarizes available details of these overwater structures.[27]

The distribution and types of overwater and in-water structures within the LDW are important to consider in this FS because they represent areas where:

- Remediation and data collection may be difficult because of restricted access, vessel interference, and armored conditions of the sediment/shoreline. Few FS baseline samples are available from beneath overwater structures, and additional data collection in these areas will be needed during the remedial design phase.
- Sediment contamination from various sources (e.g., bank erosion, stormwater discharges, groundwater/seep transport, spills, poor BMPs, or sediment deposition) could accumulate over time. This represents a data gap that will be filled, where necessary, during the remedial design phase.
- Marine structures such as piles, sheet-pile walls, pipelines, cables, and foundations may be damaged or undermined by sediment removal.
- Remedial alternatives may have to be engineered to allow navigation depths to be maintained.
- Vessel maneuvering, including vessels used for remediation, can cause scour.
- Piles, moored vessels, floating docks, and other structures may need to be removed or modified to implement the remediation.
- Vertical and horizontal clearances may impact traffic related to remedial operations (e.g., delivery of dredged material to an off-loading facility or of capping material to the project site).

Necessary remediation in areas with overwater and in-water structures will be coordinated with source control efforts and other remediation work.

The majority of overwater structures in the LDW are within Reach 1 (RM 0.0 to RM 2.2). The primary overwater structures in this reach are wharves used for the shipment and receipt of bulk materials such as cement, coal, gypsum, sand and gravel, rock lime, lumber products, and scrap metal. In total, 8 such land-based companies operate along the LDW, and 12 associated wharves or piers on both sides of the LDW currently serve

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[27] Approaches for cleanup near and beneath overwater structures are discussed in Section 7 of this FS as they relate to the evaluation of remedial technologies and development of applicable remedial alternatives for the LDW.

these operations within Reach 1. Other overwater structures in operation within Reach 1 support the shipment and/or receipt of seafood, containerized and other cargo, and construction equipment, as well as the moorage of private and commercial vessels. The Duwamish Shipyard, located on the west side of the LDW at about RM 1.4, formerly operated a wharf, marine railway, graving dock (dry dock), and two floating dry docks. The graving dock was subsequently filled in after the shipyard ceased operations. In-water structures include a pile field and pile and dolphin groups at RM 0.2 and around Kellogg Island. Overhead utility crossings occur at two locations in this reach (RM 0.4 and RM 1.95). Submerged sewer lines are located near the downstream end of this reach at RM 0.4, while submerged cable and pipeline crossings are located further upstream at RM 1.9. The First Avenue Bridge (State Route 99) crosses the LDW in two spans at RM 2.1 to RM 2.2. Its supporting structures are located in-water, with barrier walls restricting vessel traffic from navigating too close to the bridge supports.

Within Reach 2 (RM 2.2 to RM 4.0), the primary overwater structures are wharves used for the shipment and/or receipt of scrap metal, lumber, and containerized cargo, as well as the moorage of floating equipment. In total, five land-based companies and seven associated wharves on both sides of the LDW serve these operations within Reach 2. Overwater structures in this reach also include buildings constructed on in-water supports (e.g., Boeing Plant 2). A new South Park Bridge is under construction between RM 3.3 and RM 3.4 just downstream of the former bridge location, and is scheduled to be finished in the fall of 2013. An overhead utility crossing is located at RM 3.6, and submerged cable and pipeline crossings occur in two areas (RM 2.85 to RM 3.0 and RM 3.15 to RM 3.4).

Within Reach 3 (RM 4.0 to RM 4.8), only three major overwater structures exist: the Duwamish Yacht Club floating docks, the Delta Marine Industries wharf, and the Boeing Slip 6 wharf. These facilities currently support moorage for recreational vessels, recreational and commercial vessel construction and repair, and barge moorage, respectively. There is also a timber pier along the west bank of the Upper Turning Basin at RM 4.6 on property owned by the Muckleshoot Tribe. An overhead utility crossing is located at RM 4.4.

2.6.4 Shoreline Conditions

The LDW study area contains a number of different types of shoreline features that will need to be considered in developing remedial alternatives for the site (e.g., riprap fronted by dock face). Known shoreline conditions of the LDW are displayed in Figure 2-29.

The extensive shoreline development affects the remedial alternatives that may be used. Open shoreline areas are also important to consider when evaluating remedial alternatives. They represent areas where habitat restoration can more easily be combined with remedial actions. However, currently armored shorelines, which may be removed for remedial activities, also present opportunities for habitat improvements. These features are also important to consider in the FS because they represent locations where:

- Pile-supported structures, outfalls, engineered or unengineered steep slopes, and vertical bulkhead walls may be damaged or undermined by sediment remediation or removal.
- Associated shoreline armoring and debris may impact the selection and implementation of remedial alternatives.
- Outfalls may require armoring of adjacent sediment caps or backfill material.
- Intertidal and riparian bank soils may contain contaminants and require remediation.
- Remediation and data collection may be encumbered because of restricted access or hardened surfaces.
- Associated shoreline armoring materials and debris may impact the implementation of remedial alternatives.
- Piles, debris, and derelict structures may have to be removed to achieve remediation goals.
- Shoreline armoring and debris may impact the selection and implementation of remedial alternatives.
- Staging of remediation equipment may be feasible.

Shoreline armoring (e.g., engineered and unengineered riprap, cobbles, broken concrete, asphalt), bulkheads (e.g., steel sheet pile, timber pile, concrete) and exposed bank fill are the general types of shoreline that exist along the LDW. Of the total 79,580 ft (15.1 miles) of LDW shoreline, represented by the east and west banks, Kellogg Island, and the southern end of Harbor Island, approximately 53,400 ft (10.1 miles) are armored shoreline, 5,280 ft (1.0 mile) are vertical bulkhead, 1,400 ft (0.3 mile) are dock face, and 19,300 ft (3.7 miles) are exposed shoreline. Dock face also overlaps the shoreline over 24,200 ft (4.6 miles). Figure 2-29 displays these features and notes the total dock face frontage (25,900 ft or 4.9 miles).

2.6.5 Shoreline and Nearshore Habitat Features

Remedial alternatives in this FS consider impacts to nearshore habitat that may occur as a result of sediment remediation activities. The substantive requirements of a number of state and federal laws and regulations impose basic constraints on nearshore in-water work including (but not limited to):

- No net loss of aquatic habitat
- Preference for intertidal (-4 to +11.3 ft MLLW), shallow subtidal (-4 to -10 ft MLLW) habitat creation
- Preference for shallow slopes
- Preference for finer substrate
- Importance of riparian vegetation.

General approaches for nearshore remediation are considered in this FS, sufficient for feasibility-level definition and evaluation of alternatives. Detailed approaches for nearshore areas would be developed in the remedial design phase.

In addition, federal, state, and tribal Natural Resource Trustees will be working to restore damaged habitat in the LDW under the Natural Resource Damages (NRD) provisions of CERCLA. To the extent possible, implementation of remedial actions will be coordinated with NRD habitat restoration activities.

2.6.6 Vessel Traffic Patterns

Various vessel traffic operates within the LDW, including tugboats moving alone or with barges/derricks, fishing vessels, bulk cargo vessels, recreational vessels such as sailboats and motor yachts, and miscellaneous vessels such as fireboats, passenger boats, and research vessels. The LDW is also frequently used by recreational boaters in kayaks.

Five bridges span the LDW and the West Waterway. Three are located in the West Waterway: the high-level West Seattle Bridge, a railroad bridge, which remains open unless a train is traversing the waterway, and the Spokane Street Bridge. Bridge opening logs for the other two bridges that cross the LDW (First Avenue Bridge and the former South Park Bridge[28]) and the Spokane Street Bridge are discussed in this section. These are opened periodically to allow the passage of vessels that exceed clearance heights. The Spokane Street Bridge (downstream of the LDW near its mouth) is operated by the Seattle Department of Transportation (SDOT). The First Avenue Bridge (at RM 2.0) is operated by the Washington State Department of Transportation

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[28] The former South Park Bridge was closed and demolished in 2010. A new South Park Bridge is under construction between RM 3.3 and RM 3.4 just downstream of the former bridge location and is scheduled to be finished in the fall of 2013.

(WSDOT). The former South Park Bridge (at RM 3.3) was operated by the King County Department of Transportation (KCDOT). Logs of bridge openings quantify the number, duration, and frequency at which large vessels move under the bridges while open. These records were reviewed to assess the degree to which vessel traffic varies throughout portions of the LDW (SDOT 2006, KCDOT 2006, WSDOT 2006).

Bridge opening logs for the Spokane Street Bridge, which has a 55-ft clearance above mean high water, record the number of vessels entering and exiting the LDW through the West Waterway and every occasion the bridge is opened. For the analysis of potential vessel impacts on the LDW, only openings for motorized vessels other than sailboats were tabulated for the period 2003 to 2005 (Table 2-13). Motorized vessels include tugboats, which have a maximum displacement of 500 tons and an average displacement of 200 tons, and container ships, which can reach 29,000 tons and have an average displacement of 3,500 tons.

Logs for the Spokane Street Bridge for the period 2003 to 2005, portions of which are summarized in Table 2-13, recorded monthly bridge openings for large motorized vessels, ranging from 93 openings in February 2005 to 261 openings in March 2003. The average number of monthly openings during the period is 146, or approximately 5 per day. Most of these openings were for tugboat-escorted vessels and barges, representing 75 to 140 per month, with an average of 104, or approximately 3 per day (SDOT 2006). These counts represent bridge openings for large vessels entering the LDW; vessels with a low clearance do not require the bridge to be opened.

Vessels entering and leaving the LDW could disturb bottom sediments while transiting the navigation channel. Multiple vessels passing in close time proximity might create a net scour effect by preventing suspended sediment from resettling to the bed. To evaluate this possibility, an analysis was conducted to determine the frequency with which vessels enter or leave the LDW within 1 hour of each other. For motorized vessels exceeding 100 tons in displacement during the period from 2003 to 2005, the average number of times per month when 2 bridge openings occurred within 1 hour was 28, representing approximately once per day, or 40% of the openings. The conclusion from this analysis is that cumulative scour potential is expected to be minimal because vessels often do not enter the LDW within 1 hour of the prior vessel entrance and because most sediment is expected to resettle in the same place given the low frequency. The logs show that regular vessel traffic is spaced from one to several hours apart, providing minimal potential for cumulative propeller scour from several subsequent passing ships.

Records for the two drawbridges located within the LDW provide evidence of vessel traffic at least as far upstream as each bridge's location:

- The First Avenue Bridge crosses the LDW at RM 2.0. It has a 41-ft clearance at the center span and 24-ft clearance at the side spans. It opened over

1,300 times annually in both 2005 and 2006, averaging less than 4 openings daily.

- The former South Park Bridge (also referred to as the 14th Avenue Bridge, which was demolished in 2010) was located at RM 3.3. It had a 34-ft clearance at the center span and 21-ft clearance at the side span; the draw spans were removed in the summer of 2010 as part of the bridge's demolition. It was opened between 700 and 800 times annually in 2005 and 2006, approximately twice daily.

Comparison of the annual openings of the Spokane Street Bridge (approximately 2,000; KCDOT 2006) and the First Avenue Bridge (approximately 1,500; WSDOT 2006) indicates that about 75% of the vessel traffic that enters the LDW berths downstream of RM 2.0 (i.e., in Reach 1). Comparison of the number of Spokane Street Bridge openings to the annual openings of the former South Park Bridge shows that 35% to 40% of the vessels entering the LDW continue upstream at least as far as RM 3.3 (former South Park Bridge) (700 to 800 annual openings compared to 2,000 at the Spokane Street Bridge, with the assumption that each opening represents one vessel).

2.6.7 Bathymetric Coverage

Bathymetric data are used to determine mudline elevations, which in turn are used to calculate sediment volumes and compare current conditions against permitted maintenance dredging depths.

Bathymetric soundings were collected for the RI in 2003 (Windward and DEA 2004). However, the spatial extent of data collection was restricted in areas where vessels and overwater structures blocked access. As a result, the GIS grid generated to display mudline elevations was incomplete because of missing data.

Thus, in this FS, data from other sources were used to complete the bathymetry coverage. These data sources included:

- A U.S. Fish and Wildlife Service GIS shapefile of the extent of the intertidal zone, based on an aerial photograph in which sediments exposed at low tide could be observed
- Mudline elevations recorded in the field during RI sample collection (by calculation of water depth and tide level)
- Soundings recorded on National Oceanic and Atmospheric Administration (NOAA) electronic nautical charts (NOAA 2008)
- Elevations recorded during a 2003 USACE bathymetry survey (USACE 2003a).

2.7 Status of Early Action Areas

In 2003, LDWG proposed seven areas as candidates for early cleanup actions (Windward 2003b). Of the seven initially proposed, five areas (or portions of them) have been designated as EAAs by EPA and Ecology and are referred to as the EAAs in this FS. The parties responsible for the five EAAs have conducted a study of each one, and cleanups have occurred at three of the five EAAs: the Duwamish/Diagonal EAA (King County 2010a), the Norfolk EAA (King County 1999b, Calibre 2009), and Slip 4 (Integral 2012). Remedy decisions have been issued by EPA for Terminal 117 and Boeing Plant 2/Jorgensen Forge. These cleanups are being implemented under EPA Consent Orders. The purpose of this section is to provide an update on the five EAAs. All five EAAs have published SCAPs and have identified investigations and work with MTCA, RCRA, or CERCLA orders, or voluntary actions for major contaminant sources and pathways. The two candidate EAAs that were not carried forward as EAAs are included in the areas being considered for remediation in this FS.

2.7.1 Duwamish/Diagonal

In 2003 and 2004, the Duwamish/Diagonal EAA at RM 0.4E was dredged (68,000 cy). In 2004, the dredged area (7 acres) was capped. These actions were conducted by King County for the Elliott Bay/Duwamish Restoration Program (EB/DRP), which was established in 1991 to implement an NRD Consent Decree. The COCs that triggered these actions were total PCBs, mercury, BEHP, and butyl benzyl phthalate. The cleanup action did not address all the contamination present in this area.

Analysis of post-action sampling data from the perimeter stations in March 2004 revealed that the 2003/2004 project dredging activities had increased surface sediment PCB concentrations around the margin of the southwestern portion of the dredge/cap area (for technology performance discussion see Section 7; for time trends, see Appendix J). The occurrence of dredging residuals in this area was consistent with observations made regarding initial dredging operations. The BMPs that were required to minimize the spread of dredging residuals were not consistently employed, which resulted in elevated PCB concentrations around the dredge footprint. After consultation with Ecology and EPA, King County selected the thin-layer placement option, also known as ENR, as the best way to reduce the elevated PCB concentrations most expediently within the 4-acre dredging residual area adjacent to the dredge/cap area. This option was implemented in 2005, when a thin layer of clean sand was placed to a minimum thickness of 6 inches over this area. Annual monitoring was performed for five years to document the effectiveness of this option and to compare it to natural recovery rates in the area surrounding the dredge/cap area, which had significantly lower dredging residuals.[29] The most recent monitoring event (2009) showed BEHP

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[29] Five years (2005 to 2009) of post-remedy monitoring data for the cap and ENR area are presented in Appendix J. Appendix F presents perimeter monitoring data for this time span.

exceedances of the SQS in 1 of 8 cap samples and in 1 of 7 ENR area samples. No other contaminants exceeded the SQS in the 2009 cap or ENR samples. The need for further cleanup for this 4-acre area is considered part of the development of the remedial alternatives. Appendix J discusses time trend data in this area and on the sediment cap. Section 7 discusses diver probing observations made of the ENR thickness during post-remedy surveys. No further action is anticipated in the FS for the 7-acre cleanup area.

The SCAP, published in 2004, identified 446 facilities in the Duwamish/Diagonal EAA drainage basin that needed to be evaluated for their potential to recontaminate sediments. Ongoing source control efforts include source tracing and business inspections as well as an Ecology study (including sampling) of exterior building paints in the Diagonal Avenue S drainage basin. Terminals 108 and 106, adjacent to the EAA, are being evaluated for potential source control actions under Ecology's Voluntary Cleanup Program (VCP). The RI provides further details on source control activities occurring in the Duwamish/Diagonal drainage basin (Windward 2010).

2.7.2 Norfolk EAA: Norfolk CSO/SD and Boeing Developmental Center South Storm Drain

A partial cleanup at the Norfolk EAA was conducted by King County in 1999. The action was conducted for EB/DRP in the vicinity of the Norfolk CSO/SD. However, this action predates the AOC for the LDW RI/FS. During this action, 5,190 cy of contaminated sediment were excavated with dredging as deep as 9 feet in one portion of the area in an attempt to remove all contamination. The area was then backfilled with 6,700 cy of clean material. Bank stability concerns precluded further excavation, leaving some sediment in place that exceeded the CSL for total PCBs. This area was backfilled up to the original grade, resulting in backfill material to depths of 9 ft or more below the mudline (King County 1999b).

In 2001, total PCB concentrations on the Norfolk CSO/SD cleanup area ranged from 31 µg/kg dw to 1,330 µg/kg dw in the upper 10 cm of sediment and reached up to 1,900 µg/kg dw in a 0- to 2-cm sample. The highest concentrations were detected in samples near the Boeing Developmental Center's south storm drain, and a source investigation was initiated.

Under Ecology's VCP, a small area immediately offshore of the Boeing Developmental Center at RM 4.9E was excavated and capped in 2003 to address the recontamination of the Norfolk CSO/SD cleanup area. During this event, Boeing removed 60 cy of sediment from a 0.04-acre area inshore of the Norfolk CSO/SD cleanup area, and in the vicinity of the Boeing Developmental Center's south storm drain just downstream of the Norfolk CSO/SD. The excavation was then backfilled with clean sand overlying a geotextile liner containing activated carbon. The cleanup did not address all the contamination present in the broader Norfolk EAA. Subsequent monitoring of surface sediment on both caps shows that PCB concentrations have since decreased. Temporal trends in contaminant concentrations in these cleanup areas are discussed in later sections of the FS. No further action is anticipated in the FS for these cleanup areas; the nearshore and downstream areas of the Norfolk EAA are being evaluated in this FS. The RI includes a discussion of the source control activities occurring in the drainage basin (Windward 2010).

2.7.3 Slip 4

The head, or eastern 3-acre sediment and riverbank portion, of the 6-acre Slip 4 (the Slip 4 EAA) was actively cleaned up by the City of Seattle under an EPA Consent Order from October 2011 through January 2012. The cleanup included:

- Dredging/excavating approximately 10,260 cy of sediments and bank material with off-site disposal
- Overexcavating bank areas to expand intertidal and riparian habitat
- Conducting pier demolition
- Removing piling and debris
- Capping the entire 3.6-acre area with 30,700 cy of clean sand and gravel to obtain a 12-in minimum cap thickness, including armor rock and 3,500 cy of granular activated carbon amended filter material
- Implementing institutional controls and long-term monitoring.

As part of implementing the selected remedy, the City of Seattle purchased much of the affected portion of Slip 4. In the summer of 2009, the City of Seattle cleaned out and replaced the Georgetown Steam Plant Flume with a pipe, which still discharges stormwater to Slip 4.

Other source control actions included cleaning catch basins and storm drain lines at King County International Airport (KCIA) and inspecting businesses and facilities at KCIA to verify that they comply with applicable regulations and BMPs. In addition to this work, from 2004 to 2007, the Boeing Company removed approximately 89,000 linear feet of PCB-contaminated concrete joint material from North Boeing Field, and in 2010 they removed an additional 3,900 linear feet of this material from the northern area of the property (Ecology 2011a). Construction of the Slip 4 EAA cleanup was undertaken after completion of these and other source control actions within the Slip 4 drainage basin.

Four surface sediment samples were collected in 2006 as part of the 2007 100% design submittal, and 13 subsurface samples were collected in 2008 for the 2010 design update (in addition to those in the RI baseline dataset). These samples are included in the FS baseline dataset.

The southwestern portion of Slip 4 is being addressed as part of the Boeing Plant 2 RCRA corrective action, which will include a habitat restoration project pursuant to an NRD settlement between the natural resource trustees and Boeing.

2.7.4 Boeing Plant 2/Jorgensen Forge

Since the early 1990s, various soil, groundwater, and sediment investigations have been conducted within the Boeing Plant 2/Jorgensen Forge EAA under RCRA for Boeing Plant 2 and under MTCA and CERCLA for Jorgensen Forge. Boeing Plant 2 is a RCRA hazardous waste treatment, storage, disposal (TSD) facility subject to RCRA permitting and regulation. A component part of all RCRA permitting is the performance of all necessary corrective action or cleanup of hazardous waste or constituents released at or from the TSD. EPA issued a RCRA AOC to Boeing in January 1994, requiring the performance of a RCRA Facility Investigation/Corrective Measures Study (RFI/CMS), to determine the nature and extent of hazardous constituent releases at or from Plant 2 requiring corrective action (also called corrective measures) and an analysis of alternative corrective measures to address those releases, as well as the implementation of Interim Measures to mitigate or correct ongoing or continuing releases in a manner consistent with future corrective action. A RCRA RFI/CMS is the functional equivalent of a CERCLA or MTCA RI/FS.

Surface sediment exceedances of the SMS criteria in this EAA included total PCBs, PAHs, phthalates, cadmium, chromium, copper, lead, mercury, phenol, silver, and zinc. Boeing Plant 2 sediments have some of the highest concentrations (thousands of µg/kg dw) of total PCBs in the LDW. Investigations of upland portions of Boeing Plant 2 have identified over 40 hazardous constituents in upland soil, groundwater, seeps, and source tracing samples.

To date, several potential sources identified during upland investigations of Boeing Plant 2 have been controlled or removed as RCRA Interim Measures under the AOC (e.g., stormwater lines have been removed and/or cleaned, and catch basins connected to the storm drain conveyance system have been routinely sampled and cleaned as needed). Soils and groundwater in some areas with elevated hazardous constituent concentrations have been removed, remedied, or contained. There have also been very limited hot-spot removals of contaminated sediments in the intertidal area offshore of Boeing Plant 2. Eleven surface sediment and 355 subsurface sediment samples were collected from 2007 to 2009 and have been included in the FS baseline dataset. These samples are in addition to those collected earlier and included in the RI baseline dataset. EPA recently approved Boeing's CMS for remediation of contaminated sediments adjacent to Plant 2 (2010). A RCRA Statement of Basis (the RCRA equivalent of a Proposed Plan for Remedial Action) containing EPA's proposed corrective action for Boeing Plant 2 sediments was released in spring 2011; this document describes alternatives for sediment remediation, with a range of 114,000 to 142,000 cy to be dredged from the northern portion of the EAA and a range of 43,000 to 86,000 cy from the southern area of the Boeing Plant 2 portion of the EAA (EPA 2011b).

The 22-acre Jorgensen Forge facility is located south (upstream) of Boeing Plant 2. In 2007, Ecology and the Jorgensen Forge Corporation (the current owner of Jorgensen Forge) negotiated an agreed order to conduct a source control investigation at the facility. Underground storage tank removals and some upland soil investigations have occurred (Ecology 2007a). Also, in 2003, EPA issued an AOC to the Earle M. Jorgensen Company (a former owner of Jorgensen Forge) for investigation and preparation of an Engineering Evaluation/Cost Analysis (EE/CA) for a non-time-critical removal action for sediments and associated shoreline bank soils. The final EE/CA was completed and approved by EPA in 2011 (Anchor QEA 2011). EPA anticipates issuing an Action Memorandum following public comment on the EE/CA, and selecting a remedy compatible with its proposed remedy for Boeing Plant 2. Amendments to Boeing's and Jorgensen's AOCs with EPA require that the Boeing Plant 2 and Jorgensen cleanups be fully coordinated to address sediments in this EAA.

2.7.5 Terminal 117

The Terminal 117 (T-117) upland area at RM 3.5W was historically used for the manufacture and storage of asphalt products. The Duwamish Manufacturing Company began manufacturing asphalt roofing materials at T-117 in the late 1930s at a location that generally corresponds with the present-day western half of the upland portion of T-117. The business and property were sold in 1978 to the Malarkey Asphalt Company, which continued operating until 1993 when industrial operations ceased. During the Duwamish Manufacturing Company's operation of the facility from the late 1960s through the mid 1970s, used oils, some of which contained PCBs, were used as fuel for the boilers in the asphalt manufacturing process. Some of the used oils came from Seattle City Light (Windward et al. 2010).

Soils on the upland portion of T-117 with elevated concentrations of PCBs were removed by the Port of Seattle with EPA oversight pursuant to separate AOCs issued by EPA for time-critical removal actions in 1999 and 2006. In addition, PCB-contaminated areas in the rights-of-way were paved, and a temporary stormwater collection system was voluntarily installed by the City of Seattle, without EPA oversight, which conveys most runoff from the roadways adjacent to T-117 to the combined sewer system.

The EE/CA for T-117 was approved by EPA on June 3, 2010. It included an analysis of alternative non-time critical removal actions for three study areas: adjacent in-water sediments, the former industrial facility upland soil and groundwater, and adjacent city streets and residential yards; along with an assessment of potential recontamination of the nearby Basin Oil facility and the South Park Marina. Data gap findings and groundwater occurrence and quality are presented in separate project documents. EPA issued its Action Memorandum for the T-117 EAA, containing removal actions for each of the three study areas, on September 30, 2010 (EPA 2010). An Administrative Settlement Agreement and Order on Consent for implementing the selected removal action was issued to the Port of Seattle and City of Seattle on June 9, 2011 (EPA 2011c).

Table 2-1 Chronology of Historical Events in the Lower Duwamish Waterway and River

Event	Event or Report Date	Notes
Duwamish River channelization	1901	Waterway construction began with filling of wetlands using regrade material from surrounding hills.
Dredging of East and West Waterways to create Harbor Island	1903-1905	
Channelization of Duwamish River into LDW	1909-1916	Present configuration by 1920.
Construction of Lake Washington Ship Canal	1916	Restricted flow of Lake Washington to the Duwamish River, redirected Cedar River from Black and Duwamish rivers to Lake Washington.
Commercial Waterway District established	pre-1920	District is responsible for maintenance of LDW.
USACE became responsible for maintenance dredging of navigation channel	1920	
Construction of Howard Hanson Dam	1961	Last flood event in 1959. Dam approximately 65 miles upstream of LDW.
Port of Seattle ownership of LDW begins	1963	
Shoreline filling	1966-1972	Slough at RM 0.5E filled, last evidence of Slips 5 and 7, first evidence of Slip 3 with geometric configuration.
Significant sewage treatment upgrades	1967-1969	Duwamish Siphon built under river to transport water from West Seattle to pump station. Duwamish Pump Station operations begin (pump water to West Point) and Diagonal Avenue Sewage Treatment Plant operation and direct discharge to the LDW ceases.
PCB transformer spill in Slip 1	1974	Sediment in and outside of Slip 1 dredged by EPA.
Last evidence of Diagonal Avenue Sewage Treatment plant structures on USACE conditions surveys	1981	
Renton Wastewater Treatment Plant no longer discharges treated effluent to the Green River.	1984	Notable releases to LDW from these sources cease.
Harbor Island secondary lead smelter closes.		
Norfolk CSO/SD EAA sediment removal and capping	1999	Sediment dredging and capping offshore of Norfolk CSO/SD at RM 4.9.
Listing of LDW as Superfund Site	2001	
Boeing Developmental Center South Storm Drain sediment removal and capping	2003	Inshore area adjacent to Norfolk CSO/SD remediated at RM 4.9.
Duwamish / Diagonal EAA sediment removal and capping	2003-2005	Dredging and capping of two areas in 2003-2004. Thin-layer of sand placement cap on adjacent area at RM 0.5 in 2005.

Sources: King County, Anchor, and EcoChem 2005b, *Duwamish/Diagonal Cleanup Study Report*; HistoryLink.org; USACE 1947 to 1981, Historical Conditions Surveys; Windward 2010, *Lower Duwamish Waterway Remedial Investigation*.

Notes:

CSO/SD = combined sewer overflow / storm drain; EAA = early action area; EPA = U.S. Environmental Protection Agency; LDW = Lower Duwamish Waterway; PCB = polychlorinated biphenyl; RM = river mile; USACE = U.S. Army Corps of Engineers

Table 2-2 FS Data Added to the RI Baseline Dataset

Sampling Event	Sample Date(s)	Number of Samples or Locations[a]	Party; Notes
Surface Sediment (FS baseline data averaged to location; count is number of locations)			
Duwamish/Diagonal EAA (perimeter stations)	2005-2009	13 (5 in 2005; 8 in 2009)	King County; most recent perimeter data in FS baseline dataset; pre-remedy cap and ENR area data in FS baseline dataset [same as in RI baseline dataset]; data from all monitoring events used in time trends analysis; post-remedy dioxin/furan composite sample from ENR area also in FS baseline dataset to increase breadth of dioxin/furan dataset.
Boeing Plant 2 EAA Western Boundary	2007	11	The Boeing Company; analyzed only for PCBs.
Terminal 117 EAA Boundary	2008	17	Port of Seattle; analyzed only for PCBs and dioxins/furans.
Slip 4 EAA Design	2006	4	City of Seattle.
LDWG dioxin/furan site-wide sampling	2009, 2010	41	LDWG; 7 discrete samples in beaches were also analyzed for PCBs, arsenic, and cPAHs; 1 additional sample (LDW-SS527, not in a beach) was analyzed for PCBs, arsenic, cPAHs, and the full suite of SMS contaminants. This event also included a collection of 6 beach sediment composite samples, but they are not part of the FS baseline dataset because they do not represent discrete samples. These data were used to update beach risk estimates and thus will be used for technology assignments (Section 8).
PACCAR / Kenworth, 8801 East Marginal Way	2006, 2008	41	Anchor QEA for PACCAR.
Industrial Container Services	2007	4	Industrial Container Services.
Terminal 115 Intertidal	2009	5	Port of Seattle.
Ecology Upstream Surface Sediment	2008	86 (8 in LDW at RM 4.9 and 5.0)	Ecology; 8 locations at RM 4.9 and 5.0 are a part of baseline dataset; locations upstream of RM 5.0 used in development of BCM input parameters (Section 5 and Appendix C).
Ecology SPI camera survey/chemistry and bioassay data (RM 0.0 to Slip 4)	2006	30	Ecology; locations also include toxicity data.
Total surface sediment chemistry location count		***174 in Study Area (does not include locations upstream of RM 5.0)***	

Table 2-2 FS Data Added to the RI Baseline Dataset (continued)

Sampling Event	Sample Date(s)	Number of Samples or Locations[a]	Party; Notes
Subsurface Sediment (number of samples; multiple samples in each core)			
Boeing Plant 2 Boundary and under building	2008, 2009	355	The Boeing Company.
PACCAR / Kenworth, 8801 East Marginal Way	2008	25	Anchor for PACCAR.
Slip 4 Early Action Area	2006, 2008	38	Landau for City of Seattle.
Terminal 115 Dredged Material Characterization	2008	11	Port of Seattle.
USACE Navigation Channel Dredged Material Characterization (data newer than RI baseline dataset)	2008, 2009	44	USACE; data used in development of BCM input parameters (Section 5).
USACE Navigation Channel Dredged Material Characterization (older data that were not in RI Baseline dataset)	1990, 1991, 1996	32	USACE; data used in development of BCM input parameters (Section 5).
Delta Marine Dredged Material Characterization	2007	4	Delta Marine.
Total subsurface sediment sample count		***509 in Study Area***	

Notes: See Figures 2-5 and 2-6a through 2-6i for sample locations.

a. Surface sediment data are averaged to location if both parent and duplicate samples exist at one location. Subsurface sediment counts are by sample because multiple samples are typically within each core. However, for core samples, parent and duplicate samples are also averaged.

BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbons; EAA=Early Action Area; ENR = enhanced natural recovery; FS = feasibility study; LDWG = Lower Duwamish Waterway Group; PCBs = polychlorinated biphenyls; RI = remedial investigation; RM = river mile; SMS = Sediment Management Standards; SPI = sediment profile imaging; USACE = U.S. Army Corps of Engineers

Table 2-3 Statistical Summaries for Human Health Risk Drivers in Sediment

Data Type/Contaminant	Summary Statistics for Sediment in the LDW (RM 0.0 to 5.0)				Total Number of Sediment Samples in FS Baseline Dataset	
	Minimum Detect	Calculated Mean[a]	Maximum Detect	Spatially-Weighted Average Concentration[a]	Total	With Detected Values
Surface Sediment						
Total PCBs (µg/kg dw)	2.2	1,136[b]	2,900,000 230,000[b]	346[b,c]	1,392 (1,390)[b]	1,309
Arsenic (mg/kg dw)	1.2	17	1,100	15.6	918	857
cPAHs (µg TEQ/kg dw)[d]	9.7	459	11,000	388	893	852
Dioxins/Furans (ng TEQ / kg dw)[e]	0.25	42	2,100	25.6	123	119
Subsurface Sediment						
Total PCBs (µg/kg dw)	0.52	1,953	890,000	n/a	1,504	1131
Arsenic (mg/kg dw)	1.2	29	2,000	n/a	531	453
cPAHs (µg TEQ/kg dw)[d]	1.2	373	7,000	n/a	542	449
Dioxins/Furans (ng TEQ / kg dw)[e]	0.15	17	194	n/a	64	64

Source: FS baseline surface and subsurface sediment dataset dated April 28, 2010 (surface) and May 14, 2010 (subsurface).

Notes:

a. The calculated mean and the SWAC use one-half the reporting limit for undetected data.

b. Mean and SWAC for total PCBs calculated with two outliers (2,900,000 and 230,000 µg/kg dw in Trotsky inlet) excluded (n = 1,390). The highest remaining concentration in the FS baseline surface sediment dataset (223,000 µg/kg dw) is located in the Norfolk area. If the two outliers were not removed, the mean would be 3,383 µg/kg dw and the SWAC would be 1,313 µg/kg dw.

c. 95% upper confidence limits on the total PCB SWAC (ranging from 544 to 702 µg/kg dw) were calculated by Kern (2010) for the interpolated RI baseline dataset using various methods. No attempt has been made to calculate 95% upper confidence limits on the SWACs for the other risk drivers.

d. cPAH TEQ calculated using compound-specific potency equivalency factors (California EPA 1994).

e. Dioxin/furan TEQ calculated using World Health Organization (Van den Berg et al. 2005) mammalian toxic equivalent factors.

cPAH = carcinogenic polycyclic aromatic hydrocarbons; dw = dry weight; FS = feasibility study; kg = kilograms; µg = micrograms; mg = milligrams; n/a = not applicable; ng = nanogram;
PCB = polychlorinated biphenyls; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 2-4 Human Health Risk-Driver Summary Statistics from Ecology Upstream Bedded Sediment Event

Risk Driver	Number of Samples (Number of Detections)	Range of Concentrations	Mean	Median	90th Percentile	UCL95
Total PCBs[a] (µg/kg dw)	73[a] (38)	2.7 U – 22	3	3	6	3
Arsenic (mg/kg dw)	74 (74)	3.7 - 16	7	6	10	7
cPAHs (µg TEQ/kg dw)	74 (60)	0.7U - 230	18	9	57	43
Dioxin/Furans (ng TEQ/kg dw)	74 (54)	0.07U - 8.4	1	0.3	3	2

Notes:

1. See Appendix C, Part 3 for all data; these data are all contained within the FS project database. Appendix C also provides a discussion of this event, its data, and how these data were used as a line of evidence for the Bed Composition Model upstream input parameters.

a. Outlier of 770 µg/kg dw for total PCBs was excluded from the dataset statistics, because it appeared to be related to an outfall.

cPAH = carcinogenic polycyclic aromatic hydrocarbons; dw = dry weight; Ecology = Washington State Department of Ecology; µg = micrograms; mg = milligrams; ng = nanograms; PCBs = polychlorinated biphenyls; TEQ = toxic equivalent; U = undetected at the reporting limit shown; UCL95 = 95% upper confidence level on the mean.

Table 2-5 Datasets Used in the FS that are not Part of FS Baseline Sediment Dataset

FS Dataset	Where Used	Where Found[a]
Composite surface sediment samples from 6 beaches collected by LDWG	Risk calculations described in Section 3 and Appendix B	Project database
CSO whole-water samples collected by King County and storm drain solids samples collected largely by Seattle Public Utilities	BCM input parameters discussed in Section 5 and Appendix C, Part 3	Additional Excel data files
Surface sediment samples and solids from centrifuged water samples collected upstream of the LDW by Ecology	BCM input parameters discussed in Section 5 and Appendix C, Part 3	Additional Excel data files
Whole water samples upstream of the LDW collected by King County	BCM input parameters discussed in Section 5 and Appendix C, Part 3	Additional Excel data files
2008 Puget Sound sediment PCB and dioxin survey (*OSV Bold* Survey) (conducted by DMMP)	Background calculations described in Section 4	Additional Excel data files
Resampled surface sediment stations in Norfolk Area EAA, Duwamish/Diagonal EAA and adjacent area (conducted by King County)	Surface sediment time trends; Section 7, Appendix F, and Appendix J	Project database
Puget Sound urban water body data (from EIM)	Surface sediment time trends described in Appendix J	Additional Excel data files
DMMP characterization of dioxins/furans outside of the LDW (provided by DMMP)	Surface sediment time trends described in Appendix J	Additional Excel data files
DMMP characterization in the LDW Upper Turning Basin (1990 – 2009; conducted by USACE)	BCM input parameters discussed in Section 5 and Appendix C, Part 3	Additional Excel data files
Data trumped by more recent co-located data in Duwamish/Diagonal or Norfolk (collected by King County)	Used in the FS baseline dataset for mapping surface sediment exceedances in Section 2, unless the data are located in Duwamish/Diagonal cap or ENR areas or in the Norfolk removal and backfill area; in these cases, the preremedy data are used in the FS baseline dataset[a]	Project database
Tissue data (compiled by LDWG)	Used in risk estimates; discussed in Appendix B	Project database
Seep and porewater data (collected by LDWG and others)	Section 4 and Appendix N	Project database

Notes:

a. The FS project database and additional Excel data files are available on http://www.ldwg.org in one zip file. The zip file also contains an index describing each dataset and its file location. Each table and dataset included in the FS project database has undergone rigorous quality control checks, as documented in technical memoranda (the most recent being Addendum 3; Windward 2012, review in progress). Other datasets are also included in the project files, but have not been formatted into the standardized set of fields included in the project database. These files are provided in Microsoft Excel format (often maintained in the same format in which they were received) and may not have undergone the same level of quality control checks as the database files.

BCM = bed composition model; CSO = combined sewer overflow; DMMP = Dredged Material Management Program; EAA = early action area; Ecology = Washington State Department of Ecology; EIM = environmental information management system managed by Washington State Department of Ecology; ENR = enhanced natural recovery; FS = feasibility study; LDW = Lower Duwamish Waterway; LDWG = Lower Duwamish Waterway Group; PCB = polychlorinated biphenyl; USACE = U.S. Army Corps of Engineers

Table 2-6 Statistical Summaries for Contaminants of Concern for Ecological Health

	Summary Statistics for Surface Sediments			Total Number of Surface Sediment Samples in FS Baseline Dataset						
Contaminant	Minimum Detect	Maximum Detect	Mean[a]	Total	With Detected Values	Detection Frequency	>SQS, ≤CSL, detected[b]	>CSL, detected[b]	>SQS or CSL, detected[b,c]	Benthic Invertebrate Risk Driver[d]
Metals and TBT (mg/kg dw)										
Arsenic	1.2	1,100	17	916	857	94%	5	9	14	yes
Cadmium	0.03	120	1.0	894	632	71%	2	12	14	yes
Chromium	4.80	1,680	42	906	906	100%	1	10	11	yes
Copper	5.0	12,000	106	908	908	100%	0	13	13	yes
Lead	2.0	23,000	139	908	908	100%	2	23	25	yes
Mercury	0.015	247	0.53	927	813	88%	20	30	50	yes
Nickel	5.0	910	28	836	836	100%	n/a	n/a	n/a	no
Silver	0.018	270	1.0	875	537	61%	0	10	10	yes
Vanadium	15	150	59	589	589	100%	n/a	n/a	n/a	no
Zinc	16	9,700	194	905	905	100%	26	19	45	yes
Tributyltin as ion	0.28	3,000	90	189	178	94%	n/a	n/a	n/a	no
PAHs (µg/kg dw)										
2-Methylnaphthalene	0.38	3,300	42	882	169	19%	1	4	5	yes
Acenaphthene	1.0	5,200	65	891	352	40%	16	4	20	yes
Anthracene	1.3	10,000	134	891	647	73%	2	0	2	yes
Benzo(a)anthracene	7.3	8,400	322	891	821	92%	10	6	16	yes
Benzo(a)pyrene	6.5	7,900	309	886	819	92%	7	5	12	yes
Benzo(g,h,i)perylene	6.1	3,800	165	891	763	86%	10	12	22	yes
Total benzofluoranthenes	6.6	17,000	732	885	829	94%	6	6	12	yes
Chrysene	12	7,700	474	891	846	95%	29	3	32	yes
Dibenzo(a,h)anthrecene	1.6	1,500	63	891	498	56%	18	6	24	yes
Dibenzofuran	1.0	4,200	54	889	276	31%	7	3	10	yes
Fluoranthene	18	24,000	889	891	868	97%	35	12	47	yes
Fluorene	0.68	6,800	78	891	431	48%	11	3	14	yes
Indeno(1,2,3-cd)pyrene	6.4	4,300	180	891	801	90%	16	13	29	yes

Table 2-6 Statistical Summaries for Contaminants of Concern for Ecological Health (continued)

	Summary Statistics for Surface Sediments			Total Number of Surface Sediment Samples in FS Baseline Dataset						
Contaminant	Minimum Detect	Maximum Detect	Mean[a]	Total	With Detected Values	Detection Frequency	>SQS, ≤CSL, detected[b]	>CSL, detected[b]	>SQS or CSL, detected[b,c]	Benthic Invertebrate Risk Driver[d]
Naphthalene	3.0	5,300	49	882	183	21%	0	2	2	yes
Phenanthrene	7.1	28,000	429	891	832	93%	27	3	30	yes
Pyrene	19	16,000	723	891	860	97%	2	6	8	yes
Total HPAH	23	85,000	3,809	891	873	98%	25	6	31	yes
Total LPAH	9.1	44,000	696	891	835	94%	4	3	7	yes
Phthalates (µg/kg dw)										
Bis(2-ethylhexyl) phthalate	5.4	17,000	590	886	704	79%	46	58	104	yes
Butyl benzyl phthalate	2.0	7,100	87	878	478	54%	80	10	90	yes
Dimethyl phthalate	2.0	440	25	878	186	21%	0	2	2	yes
Chlorobenzenes (µg/kg dw)										
1,2,4-Trichlorobenzene	1.6	940	19	871	6	1%	0	2	2	yes
1,2-Dichlorobenzene	1.3	670	19	871	19	2%	0	4	4	yes
1,4-Dichlorobenzene	1.5	1,600	23	871	50	6%	0	4	4	yes
Hexachlorobenzene	0.4	95	17	874	46	5%	4	2	6	yes
Other SVOCs and COCs (µg/kg dw)										
2,4-Dimethylphenol	6.1	290	44	869	29	3%	0	25	25	yes
4-Methylphenol	4.8	4,600	44	883	116	13%	0	4	4	yes
Benzoic acid	54	4,500	238	876	111	13%	0	9	9	yes
Benzyl alcohol	8.2	670	49	867	30	3%	9	7	16	yes
Carbazole	3.2	4,200	82	775	425	55%	n/a	n/a	n/a	no
n-Nitrosodiphenylamine	6.5	230	27	871	24	3%	0	2	2	yes
Pentachlorophenol	14	14,000	122	840	30	4%	1	1	2	yes
Phenol	10	2,800	91	886	282	32%	19	6	25	yes

Table 2-6 Statistical Summaries for Contaminants of Concern for Ecological Health (continued)

	Summary Statistics for Surface Sediments			Total Number of Surface Sediment Samples in FS Baseline Dataset						
Contaminant	**Minimum Detect**	**Maximum Detect**	**Mean[a]**	**Total**	**With Detected Values**	**Detection Frequency**	**>SQS, ≤CSL, detected[b]**	**>CSL, detected[b]**	**>SQS or CSL, detected[b,c]**	**Benthic Invertebrate Risk Driver[d]**
Pesticides (µg/kg dw)										
Total DDTs	0.72	77,000	462	216	87	40%	n/a	n/a	n/a	no
Total chlordanes	0.20	230	268	216	28	13%	n/a	n/a	n/a	no
Aldrin	0.01	1.6	27	216	4	2%	n/a	n/a	n/a	no
Dieldrin	0.10	280	29	218	8	4%	n/a	n/a	n/a	no
alpha-BHC	0.14	1.8	1.1	207	3	1%	n/a	n/a	n/a	no
beta-BHC	0.09	13	1.2	207	4	2%	n/a	n/a	n/a	no
gamma-BHC	0.05	8.6	27	216	12	6%	n/a	n/a	n/a	no
Heptachlor	0.12	5.2	27	216	6	3%	n/a	n/a	n/a	no
Heptachlor epoxide	0.47	4.9	2.8	207	4	2%	n/a	n/a	n/a	no
Toxaphene	340	6,300	111	205	2	1%	n/a	n/a	n/a	no
Total PCBs (µg/kg dw)										
Total PCBs[e]	2.2	223,000	1,136	1,390	1,309	94%	336	179	515	yes

Source: Feasibility study baseline surface sediment database queries, RM 0 to 5.0.

Notes:

a. Calculated mean concentration is the average of detected concentrations and one-half the reporting limit for non-detected results.

b. For non-polar organic compounds, comparisons to SQS and CSL were made using organic carbon-normalized concentrations. If total organic carbon in the sample was <0.5% or >4%, dry weight concentrations were compared to the LAET and 2LAET.

c. Sum of samples with SQS (but less than CSL) exceedances and samples with CSL exceedances.

d. Contaminants identified as risk drivers for the benthic invertebrate community (RAO 3) are those with one or more surface sediment samples with exceedances of the SQS. Three additional contaminants (total DDTs, total chlordanes, and nickel) that do not have SMS criteria were also identified as COCs for the benthic community.

e. Total PCB statistics and counts were generated with two outliers (2,900,000 and 230,000 µg/kg dw in Trotsky inlet) excluded. Sample count with outliers included is 1,395.

2LAET = second lowest apparent effects threshold; BHC = benzene hexachloride; COCs = contaminants of concern ; CSL= cleanup screening level; dw = dry weight; DDT = dichlorodiphenyl-trichloroethane; FS = feasibility study; HPAH = high molecular weight polycyclic aromatic hydrocarbon; kg = kilograms; LAET= lowest apparent effects threshold; LPAH = low molecular weight polycyclic aromatic hydrocarbon; µg = micrograms; mg = milligrams; n/a = not applicable; nc = not calculated; RAO = remedial action objective; SQS = sediment quality standard; SVOC = semivolatile organic compound; TBT = tributyltin; TEQ = toxic equivalent; VOC = volatile organic compound

Table 2-7 Upland Engineering Studies with In-Water Geotechnical Data and Borings

River Mile	Study/ Report Year	Study Name	Author	Area	Data Type(s)	No. of In-water Borings	Purpose of Study
0.0	1973	West Seattle Freeway Seismic Studies	SPU, Shannon and Wilson	RM 0.0-0.2	Boring logs, SPT	2	pile load test and seismic studies
0.0	1974	West Seattle Freeway Pile Load Test Program				1	
0.0	1968	Soils and Foundation Report Duwamish East Waterway Fill Industrial Terminal No. 2	Shannon and Wilson	RM 0.0E	Boring logs, SPT, grain size analysis, triaxial compression test, mohr strength envelope, consolidation test, liquid limit, subbottom profiling, bottom contour map, isopach of mud thickness	5	Fill area for terminal
0.1	1968	Lone Star Cement Site Plan	Shannon and Wilson, Soil Mechanics and Foundation Engineers	RM 0.0-0.2	Boring logs, cross sections, water content, grain size analysis	2	Proposed clinker storage silo and mill bldg construction
0.2	1993	Measured Sections and Drillhole Descriptions, Geologic Map of Surficial Deposits in the Seattle 30'x60' Quadrangle	Yount et al.	RM 0.0-0.2	Boring logs	2	Major unit mapping
0.4	1970	South Substation to Delridge Substation	Seattle Eng. Dept.	Kellogg Island	Several upland borings, no report text	1	no report text, could not determine purpose
0.4-0.5	1988	Report of Geotechnical Investigation, Port of Seattle, Terminal 108 Site, for LaFarge Canada	Dames and Moore	Kellogg Island	Boring logs, blow counts, shear test, grain size analysis	2	Proposed cement silos
0.4	1972	Diagonal	Seattle Eng. Dept.	Kellogg Island	Several upland borings, no report text	1	no report text, unknown purpose
0.4-0.5	1966-1971	Diagonal Yard	SPU	Kellogg Island	Boring logs, test pit logs, sludge pond probes	5	could not determine from materials

Table 2-7 Upland Engineering Studies with In-Water Geotechnical Data and Borings (continued)

River Mile	Study/ Report Year	Study Name	Author	Area	Data Type(s)	No. of In-water Borings	Purpose of Study
0.4-2.1	1965	SW Marginal Way between SW Spokane & S Kenyon St (GeoNW name, logs are by bridge, no report name given)	Seattle Eng. Dept.	First Ave Bridge	Only boring logs, no report text	3	no report text, unknown purpose
0.5-0.8	1968	Report of Preliminary Soils Investigation, Proposed Kellogg Island Development	Dames and Moore	Kellogg Island	Boring logs, cross sections, triaxial test (moisture content, dry density, cell pressure, deviator stress), direct shear test, consolidation test, moment coefficient	4	Development on Kellogg Island
0.6-1.0	1970	Soils and Foundation Investigation for Proposed Terminal 107 (Kellogg Island)	Twelker & Assoc.	Kellogg Island	Cross sections (poor scan quality)	6	Development of Terminal 107
1.4	1967	Foundation Investigation for Waterfront Development at 5900 West Marginal, Kaiser Cement and Gypsum	Twelker & Assoc.	Glacier Northwest, Inc.	One in-water boring to >90 ft below mudline, cross sections, SPT	1	Pier construction investigation
1.4-1.5	1979	Subsurface Exploration and Geotechnical Engineering Study for Proposed Additions to the Seattle Finish Grinding Facility	Hart Crowser	Glacier Northwest, Inc.	General description of subsurface conditions, cone penetration resistance, friction ratio, boring logs, SPT, grain size analysis, plasticity index vs. liquid limit, stress vs. strain	3	Proposed clinker storage silo, finish mill, feed bins, truck-rail unloading hopper, ship unloading facility, clinker conveyor system
2.0	1993	Geotechnical Report First Ave S Bridge Utilidor Relocate	Seattle Eng. Dept.; Shannon and Wilson	First Ave Bridge	Boring logs, cross section, SPT	2	Utilidor relocation in conjunction with seismic retrofitting of existing bascule bridge and construction of parallel bridge to the west
2.0-2.1	1992	Geotechnical Report, Preliminary Explorations and Engineering Studies, First Avenue South Bridge Over Duwamish	Shannon and Wilson	First Ave Bridge	Boring logs, SPT, cross sections, piezocone probe data, grain size analysis, plasticity index	2	Bridge construction

Table 2-7 Upland Engineering Studies with In-Water Geotechnical Data and Borings (continued)

River Mile	Study/ Report Year	Study Name	Author	Area	Data Type(s)	No. of In-water Borings	Purpose of Study
2.0-2.1	1972	Kenyon to First Avenue, Proposed 72" Utilities Tunnel	WSDOT	First Ave Bridge	Boring logs, deep cross section	5	Utilities tunnel construction
2.2	1961	Northwest Cooperage Foundation Exploration	Twelker & Assoc.	RM 2.2W	Boring logs	4	Foundation exploration
4.7	1988	Geotechnical Design Report, North Oxbow Bridge, Boeing Developmental Center	Rittenhouse-Zeman & Assoc.	RM 4.7	Written text (general riverbank condition), liquefaction test, SPT, logs, cross section, bathymetry	3	Bridge construction

Notes:

1. Logs and portions of reports from GeoNW website. http://geomapnw.ess.washington.edu/index.php

RM = river mile; SPT= standard penetrometer test; SPU= Seattle Public Utilities; WSDOT= Washington State Department of Transportation

Table 2-8 Trace to Abundant Debris and/or Sheen in 2006 RI Sediment Cores

2006 Core	Debris and/or Sheen Description	Debris	Sheen
SC-2	Trace hydrocarbon-like sheen from 1.2 to 4.1 ft; rock flour (100%) from 4.3 to 10.5 ft.	X	X
SC-4	Trace hydrocarbon-like sheen from 1.4 to 2.5 ft.		X
SC-11	Red chips, 1 piece of plastic & leather, 2 glass shards, and cedar chips from 0 to 0.9 ft; dark grey gravel from 4.1 to 4.9 ft.	X	
SC-13	Layer of shredded wood with fibrous peat-like material from 5.5 to 6.0 ft.	X	
SC-14	1/16" sheen florets from 0.3 to 3.7 ft and from 4.1 to 8.7 ft.		X
SC-15	Trace hydrocarbon florets and blebs up to 1/2" long from 1.2 to 2.0 ft.		X
SC-16	Trace 1/16" sheen florets from 1.3 to 2.0 ft; garbage bag at 0.5 ft; trace odor and sheen from 4.0 to 7.4 ft.	X	X
SC-17	Layers of wood and abundant debris from 0.9 to 12.3 ft; rainbow sheen on core side walls from 2.0 to 6.0 ft.	X	X
SC-18	Glass shard 0.2 ft long at 0.8 ft; subangular rock 0.3 ft long at 1.5 ft; 1" layer of wood fragments up to 3/4" long at 8.6 ft.	X	
SC-19	Rainbow sheen florets up to 1/4" long and wood fragments up to 1" long at 1.9 ft; rainbow sheen on side walls of core from 0.8 to 7.0 ft.	X	X
SC-20	Trace hydrocarbon-like sheen from 0.1 to 4.7 ft.		X
SC-21	Scattered wood layers up to 0.1 ft thick with orange-brown shredded wood from 10.1 to 12.7 ft.	X	
SC-22	Trace debris from 0 to 1.3 ft; moderate creosote-like sheen and hydrocarbon staining from 1.3 to 2.0 ft; abundant wood fragments at 2 ft; scattered debris from 2.0 to 9.3 ft w/ 3" brick fragment at 3.6 ft.	X	X
SC-23	Trace debris from 0 to 0.5 ft.	X	
SC-25	Layers of 4" long shredded wood fragments from 0.4 to 5.5 ft; glass shard at 1.8 ft.	X	
SC-26	Large gravels with hydrocarbon-like sheen and scattered debris from 7.9 to 9.1 ft; scattered debris and florets from 9.1 to 13.1 ft.	X	X
SC-28	Black, loose sand blast grit and scattered debris from 5.8 to 12.8 ft; grit left metallic sheen on core side walls from 4.0 to 11.3 ft.	X	X
SC-32	Trace wood fragments up to 4" long with slight hydrocarbon-like sheen florets from 3.5 to 5.1 ft.	X	X
SC-33	Trace black sheen from 0.3 to 1.8 ft; trace debris from 2.8 to 10.0 ft.	X	X
SC-34	Trace debris from 0.7 to 11.3 ft.	X	
SC-37	Trace debris and wood fragments from 0.3 to 2.6 ft; metallic and hydrocarbon sheens up to 1" long from 3.2 to 6.3 ft.	X	X
SC-38	Moderate to heavy hydrocarbon-like sheen in sand seams from 2.5 to 3.8 ft; scattered wood debris from 0.0 to 2.5 ft and from 3.8 to 5.6 ft.	X	X
SC-39	Trace debris from 0.4 to 2.5 ft; wood fragments up to 1/2" long from 3.9 to 7.5 ft; trace wood fragments up to 7" long from 7.5 to 10.3 ft.	X	
SC-40	Trace debris from 1.7 to 13 ft.	X	
SC-41	Wood fragments up to 4" long and scattered 1/2" sheen florets from 2.2 to 6.9 ft.	X	X
SC-42	Shredded wood from 0.2 to 4.0 ft; 3" layer of silt with black sheen at 3.4 ft; black sheen from 8.0 to 11.8 ft; piece of plastic at 11.0 ft.	X	X
SC-44	1" glass shards and little debris from 2.4 to 4.8 ft; 6" subangular conglomerate at 3.3 ft.	X	
SC-45	Scattered rainbow sheen florets from 2.2 to 4.1; 2" long concrete piece at 4.8 ft; trace debris from 5.2 to 7.5 ft; drive 2 close to shore had heavy sheen in gravel layer at 4 ft and free phase blebs.	X	X
SC-46	Trace debris from 2.3 to 7.9 ft; metallic sheen at 2.8 ft; rainbow sheen at 3.6 ft.	X	X
SC-47	Up to 1" long trace debris from 0.7 to 2.9 ft.	X	
SC-50	2" layer of black gravel at 1.3 ft; subangular gravel at wood fragments and gravel from 1.3 to 4.2 ft.	X	
SC-51	Scattered hydrocarbon-like sheen florets and streaks up to 1" long from 0.0 to 0.4 ft; scattered debris including brick fragment from 1.7 to 5.0 ft.	X	X
SC-53	Trace possible anthropogenic fibers at 5.2 ft.	X	
SC-56	Trace hydrocarbon-like sheen above 1" silt seam at 1 ft; abundant wood fragments 3.8 to 7.0 ft.	X	X

Notes:

▨ Significant (>50% by volume) anthropogenic material / debris or abundant large gravels.

ft = feet; RI = remedial investigation

Table 2-9 LDW Navigation Channel Maintenance Dredging (1986 to 2010)

	Dredge Date				Survey Dates		
River Mile	Start	End	Volume Dredged (cy)	Paydepth / Overdepth (ft MLLW)	Pre-Dredge	Post-Dredge	Side Slope
4.19 to 4.38	03/11/86	03/29/86	33,637	-16 / -18	—	—	—
4.38 to 4.65	06/19/86	7/15/1986	126,470	-16 / -18	—	—	—
4.38 to 4.65	02/24/87	03/24/87	80,160	-18 / -20	—	—	—
3.97 to 4.65	02/28/90	03/30/90	127,619	-17	—	—	2:1
3.34 to 4.65	02/06/92	03/21/92	199,361	-15 / -17	—	—	3:1
4.33 to 4.65	03/07/94	03/28/94	57,243	-15 / -17	1/21/1994	4/6/1994	2:1
4.02 to 4.48	02/22/96	03/30/96	90,057	-15 / -16	2/14/1996	4/2/1996	2:1
4.26 to 4.65	02/05/97	03/31/97	89,011	-15 / -16	1/23/1997	—	2:1
3.43 to 4.65	03/11/99	06/29/99	165,116	-15 / -16	3/5/1999	7/8/1999	2:1
4.27 to 4.65	01/14/02	02/09/02	96,523	-15 / -16	1/3/2002	2/20/2002	2:1
4.33 to 4.65	01/15/04	02/16/04	75,770	-15 / -17	12/17/2003	2/14/2004	3:1
4.27 to 4.65	12/11/07	01/10/08	140,608	-15 / -16	—	—	—
4.18 to 4.65	02/19/10	3/30/10	60,371	-15 / -17	Oct. 2008 and Aug. 2009	5/24/2010	—

Sources:

USACE Dredge Summary and Analysis Reports (USACE 2005), *2009 Suitability Determination* (DMMP 2009a), and *2010 Payment Summary* (USACE 2010a).

Notes:

1. See Figure 2-27 for locations of dredging events.

cy = cubic yards; ft = feet; MLLW = mean lower low water; RM = river mile; USACE = U.S. Army Corps of Engineers; — = unknown or no survey conducted

Table 2-10 Overwater Structures, Moorages, and Other Physical Structures

Structure	River Mile	River Side	General Type[a]	Use	Recorded Water Depth (ft MLLW)	Authorized Navigation Channel Depth Adjacent to Berthing Area (ft MLLW)	Breasting Distance (ft)[b]
Harbor Island Marina	0	W	Marina	Recreational and commercial vessel moorage	—	-30	—
Glacier Northwest South Wharf (Terminal 103)	0	W	Timber bulkhead with solid fill fronted by timber pile wharf, steel transfer bridge	Receipt of sand, gravel, and stone	-10	-30	240 (face)
Ash Grove Cement North Wharf	0.1	E	Timber pile, concrete decked wharf	Shipment of bulk cement	-25	-30	600 with dolphins
Ash Grove Cement South Pier	0.2	E	Steel pile, timber decked pier	Receipt of coal, gypsum, gravel, and rock lime	-25	-30	225
Berth No. 1 Wharf (Terminal 105)	0.3	W	Steel sheet pile bulkhead, asphalt-surfaced solid fill	Receipt of scrap metal	-40	-30	660 (face)
Berth No. 2 Wharf (Terminal 105)	0.4	W	Timber bulkhead with solid fill fronted by timber pile timber-decked wharf	Mooring vessels	-15	-30	450
Tilbury Cement East Marginal Terminal Wharf	1.0, adjacent to Manson wharf	E	Concrete pile, concrete-decked wharf	Receipt of bulk cement and gravel	-17	-30	300
U.S. Government Wharf	1.0, north side Slip 1	E	Timber bulkhead, solid fill, concrete-decked extensions	Mooring vessels / previously used for containerized shipments	-26 (face); 0 to -26 (west side); -15 to -26 (head of slip)	-30	642 (face); 165 (head of slip)
Manson Construction Wharf	South side Slip 1 and 1.0, just south of Slip 1	E	Concrete bulkhead, solid fill, concrete-decked extensions	Mooring floating equipment and dredge, moving supplies to and from barges	-12 to -20 (face); -20 (west side dolphins)	-30	550 (face); 300 (west side dolphins)
Lafarge Corporation Raw Materials Wharf	1.0 to 1.25	W	Steel sheet pile, cellular bulkhead	Receipt of limestone, shale, coal, and slag	-30	-30	1,100
Lafarge Corporation Cement Wharf	1.0, south of Kellogg Island	W	Three timber piles, timber decked offshore wharves, connected by timber catwalks	Receipt and shipment of bulk cement	-32	-30	645 with dolphins (center wharf)
J.A. Jack and Sons Wharf	1.2	E	Offshore row of 6 timber dolphins, catwalk	Receipt of limestone	-20	-30	250
Alaska Marine Lines Dock No. 1	1.25	W	Concrete, timber, steel piles, concrete-decked wharf	Containerized general cargo	-20 to -25	-30	325
Duwamish Shipyard Graving Dock Wharf	1.3	W	Wharf: concrete and timber pile bulkhead; historical graving dock (subsequently filled in): steel sheet pile retaining walls, concrete floor, steel gate	Mooring vessels for repair / previous shipment of concrete fabrications and mooring vessels	-20 (pier)	-30	400 by 138 (graving dock); 60 (pier)
General Construction Mooring	1.4	E	Offshore row of 11 timber dolphins	Mooring floating equipment and barges	-17	-30	800
Duwamish Shipyard Wharf	1.4	W	Irregularly shaped timber pile, timber-decked offshore wharf, timber floats connect dolphins, dredged basin at rear of dolphins on south side	Mooring vessels for repair, mooring dry docks	-25 (face); -20 to -25 (basin)	-30	500 with dolphins
Glacier Northwest West Terminal Wharf	1.5	W	Concrete pile, concrete-decked offshore wharf with concrete-decked approach	Receipt of bulk cement	-34 to -40	-30	467
James Hardie Gypsum Wharf	1.6	E	Steel and timber pile, timber-decked wharf extending from steel sheet pile bulkhead with solid fill	Receipt of bulk cement and gypsum rock	-30 to -31 (face); -6 to -32 (south face); -11 to -32 (north side)	-30	400 with dolphins
Northland Services (Terminal 115)	1.5 to 1.9	W	Berth 1: Piers A and C center timber pier, Pier B ramp support structure and A-Frame and upgrade fendering systems.	Barge loading and unloading	-15	-30	Proposed modification, not constructed yet
International Terminal North Wharf (Terminal 115)	1.6 to 1.8	W	Concrete piles support 103-ft wide concrete apron over water. Riprap slope and sheet pile bulkhead on inner land side.	Containerized general cargo and heavy lift items; receipt of steel products; receipt and shipment of forest products	-40	-30	1,200
Glacier Northwest Slip 2 Wharf	1.7, north side Slip 2	E	Timber pile, timber-decked offshore wharf, adjustable transfer bridge	Receipt of sand and gravel	-16 to -17	-30	325 with dolphins
South Wharf (Terminal 115)	1.8	W	Three timber pile, timber-decked loading platforms fronting concrete bulkhead	Containerized general cargo and heavy lift items	-14	-30	490
Filter Engineering Wharf	1.8, south side Slip 2	E	Steel/timber pile, timber-covered, concrete-decked offshore wharf	Moving construction equipment to and from barges	-12	-30	130 with dolphins
Seafreeze Limited Partnership Wharf (Terminal 115)	1.9	W	Concrete pile, concrete-decked offshore wharf with concrete approach and steel catwalks	Receipt of fish and seafood	-20	-30	100
Alaska Marine Lines Dock No. 2	2.1	W	Concrete pile, concrete-decked wharf	Containerized general cargo; mooring vessels	-15	-20	400 with dolphins
Northland Services Fox Avenue Terminal Wharf	2.1 to 2.2, south of and on south side of Slip 3	E	Concrete pile, concrete-decked wharf extending from sheet pile bulkhead	Conventional and containerized general cargo	-18	-20	475 (slip side); 500 (river side)
Silver Bay Logging South River Street Wharf	2.1, north side Slip 3	E	Timber pile, timber-decked wharf extending from timber bulkhead	Mooring barges	-15	-20	215
Boyer Alaska Barge Line Mooring	2.3	W	Two offshore breasting dolphins fronting natural bank	Mooring floating equipment	-10	-20	175
MC Halverson Marina	2.3	W	Marina	Residential vessel moorage	—	-20	—
Seattle Iron & Metals North Wharf	2.4	E	Timber pile, asphalt-surfaced, timber-decked wharf extending from steel sheet pile bulkhead	Receipt of scrap metal by barge	-12 to -13	-20	125

Table 2-10 Overwater Structures, Moorages, and Other Physical Structures (continued)

Structure	River Mile	River Side	General Type[a]	Use	Recorded Water Depth (ft MLLW)	Authorized Navigation Channel Depth Adjacent to Berthing Area (ft MLLW)	Breasting Distance (ft)[b]
Boyer Alaska Barge Line Seattle Wharf	2.4	W	Timber bulkhead, asphalt surfaced solid fill with timber pile, timber-decked extension	Containerized general cargo, lumber, mooring tugs and barges	-10	-20	300 with dolphins
Seattle Iron & Metals South Wharf	2.5	E	Timber pile, asphalt-surfaced, timber-decked wharf extending from steel sheet pile bulkhead	Receipt of scrap metal by barge	-16	-20	300
Alaska Washington Building Materials Co. Wharf	2.5	W	Irregularly shaped concrete bulkhead with solid fill, fronted by three timber dolphins	Not used / previously receipt of sand and gravel	-2 to -12	-20	100+25
Hurlen Construction Mooring	2.65	W	Natural bank with shore moorings	Mooring floating equipment, moving supplies to and from barges	-8 to -20	-20	200
Hurlen Construction Wharf	2.7	W	Timber pile, timber-decked wharf	Mooring floating equipment, moving supplies to and from barges	-20	-20	280 with dolphins
Northland Services 8th Avenue Terminal Wharf	2.8, north side Slip 4	E	Concrete pile, concrete-decked wharf	Conventional and containerized general cargo	-13 to -15	-15	165, 390, 480 along face
Silver Bay Logging 8th Avenue Wharf	2.9	W	Steel pile, steel beam, timber and steel grating decked wharf	Receipt of lumber by barge	-18	-15	400 with dolphins
Boeing Plant 2	3.1 - 3.5	E	Two buildings	Historical overwater buildings	n/a	-15	n/a; not used for moorage
South Park Marina	3.4	W	Marina	Moorage of commercial and recreational vessels	-8	-15	~900
McElroy George and Assoc.Inc.	4.0	W	Marina	Vessel moorage	—	-15	—
Northwest Container Services	4.1	E	Dolphins for mooring	Moorage of barges	—	-15	—
Duwamish Yacht Club	4.1	W	Marina	Moorage of recreational vessels	-8	-15	620 x 320
Delta Marine Industries Wharf	4.2	W	Offshore row of permanently moored floats, approach from concrete-paneled bulkhead	Mooring vessels for outfitting and repair; fiberglass vessels manufactured on site	-10	-15	284 (face); 160 (rear); 230 (bulkhead)
The Boeing Company Seattle Wharf	4.3, Slip 6	E	Six concrete pile, concrete-decked, asphalt-surfaced loading platforms	Mooring barges; previously not used	-18	-15	650 total
Various structures	0.15 to 0.2	W	Abandoned pile fields associated with historical vessel launch facilities. At least 500 abandoned single piles appear to be in this area.		n/a		
	0.43 to 0.48	Both	Submerged sewer line crossings				
	0.38 to 0.47	Both	Overhead power cable crossings. Authorized vertical clearances are in excess of 90 ft at each installation.				
	1.95						
	3.6						
	4.4						
	0.6 to 0.9	W	Pile group along Kellogg Island's west side				
			Pile and dolphin groups along Kellogg Island's east side				
	1.8 to 2.1	Both	Submerged cable and pipeline area				
	2.1 to 2.2	Both	First Avenue bascule bridges. The west and east bridges have 145-ft horizontal clearance closed and 120-ft horizontal clearance open. Vertical clearance is 22 ft (39 ft at center) when closed.				
	2.85 to 3.0	Both	Submerged cable area				
	3.15 to 3.4	Both					
	3.3 to 3.4	Both	South Park bascule bridge. Also known as the 14th/16th Ave South Bridge, this bridge had a 92-ft horizontal clearance, and 21-ft vertical clearance (34 ft at center) (NOAA 2008). The former bridge was demolished and a new bridge is under construction just downstream of the former bridge location, with completion scheduled for fall of 2013.				
	Throughout		Abandoned and working piles and dolphins throughout the LDW				

Source: *Port Series No. 36* (Revised 2002) – Port of Seattle, Washington; U.S. Army Corps of Engineers Institute for Water Resources; NOAA 2008. NOAA Chart 18450, Edition 18, 2/1/2004, Updated 2/2/2008; additional sources used include: field surveys, 2002 aerial photograph, DMMO memos, and Remedial Investigation (Windward 2010).

Notes:

1. See Figure 2-28 for locations of berthing areas.

a. Structure type is general. See Port Series for additional details.

b. Breasting distance is the length in ft of the portion of the structure to which a vessel berths.

DMMO = Dredged Material Management Office; E = east; ft = feet; LDW = Lower Duwamish Waterway; MLLW = mean lower low water; NOAA = National Oceanic and Atmospheric Association; RM = river mile; W = west

Table 2-11 History of Private Maintenance Dredging Events in the LDW (1980 to 2008)

Project/Site Name	River Mile	River Side	Dredge Year	Volume Dredged (cy)	Pay Depth / Overdepth (ft MLLW)	Purpose	Suitable for Open-water Disposal?	Source Type		Permit
								Pre-dredge Documents[a]	Post-dredge Confirmation[b]	
Terminal 103	0.46 to 0.56	W	2005	1,350	-14/-15	Navigation	—	x		—
Lone Star/Current Ash Grove Location	0.2	E	began in March 1980 (with add'l in 1983)	5,000 allowed; 4,000 by 1981	-35	Maintenance dredging event for clinker ship unloading	Dredged material used as raw material in cement kiln	x	x	071-0YB-1-005983: issued in 1980
Lafarge	0.98	W	2009	1,000	—	Maintenance dredging event	—			—
Lehigh Northwest	1.0 to 1.1	E	2004	9,000	-20 / -21	Maintenance dredging event	DMMUs 1 and 3 (6,000 cy) suitable DMMU 2 (3,000 cy) not suitable	x		—
Duwamish Shipyard	1.39 to 1.42	W	Last event in 1982	—	-25 to -15	Maintain depth of basin behind dolphins	—		x	—
Glacier Northwest, Inc.	1.42 to 1.54	W	2005	9,920	-34 (pay depth authorized to -35)	Maintenance dredging and thin-layer cap	DMMU 1 (3,250 cy) suitable DMMUs 2 and 3 (6,670 cy) not suitable (capped)	x	x	92-2-00452: 3,900 cy in 1993; 4,000 cy in 1997 (in original permit, but removed from revision, so assume did not occur, also not mentioned in 2005 document); can go up to 10,000 additional cy to 2003 (with permit revision); permit allows maintenance to -35' in whole area, but shows only small area dredged in 1993.
Lone Star Northwest-West Terminal	1.43 to 1.52	W	1993	3,900	-35 / -36	Maintenance dredging event	Yes	x	x	
Lone Star Northwest-West Terminal	1.43 to 1.52	W	1986	—	—	Maintenance dredging event	No, taken to upland site		x, mentioned in reports for later events	
James Hardie Gypsum	1.56 to 1.75	E	1999	10,000 permitted	-31	Maintenance dredging event	4,540 of 7,042 cy suitable	x		Same permit as 95-2-00837 below, issued in 1996, authorized 10 years of dredging, 1999 is first dredging event since 1996
Lone Star-Hardie / Kaiser	1.55 to 1.75	E	1996	18,000	-30 / -31	Maintenance dredging event & dock upgrade	DMMUs 1-3 (9,375 cy) not suitable DMMUs 4 and 5 (8,625 cy) suitable	x	x	95-2-00837: 95-4-00837 revision (August 1996) for 3 dolphins, 28 piles, and walkway extension; annually dredge additional 9,000 cy for upland disposal in upstream portion of footprint (DMMUs 1-3); shows previous dredge at downstream end (DMMUs 4-5 for in-water disposal).
Lone Star-Hardie / Kaiser	1.6 to Slip 2	E	1986 (unconfirmed)	26,000	-30 (dock), -16 (Slip 2)	Ramp, conveyer, dolphin construction	—		x	071-OYB-2-009121: area in front of dock and Slip 2 to construct ramps, conveyers, dolphins; no confirmation this occurred. PCB concentrations too high for open-water disposal. Dredging footprint modified. No map found of dredging footprint.
Glacier Ready Mix	Slip 2	E	2001	4,900	-15 /-16	Maintenance dredging event	Yes			—
Lone Star Northwest Slip 2	Slip 2	E	1990	1,600	-14	Maintenance dredging event	Yes	x	x	071-OYB-2-013065: 1,600 cy first year (1990) then 1,000 cy each year for 9 years for a max of 10,600 cy, 1994 modification to 3,000 cy; HPA #B2-13065-03: issued in 1990 and revised in 1994 to retrieve spilled aggregate; 1994 Dept. of Ecology water quality modification #DE 94ER-008.
		E	1991	1,100	Not specified	Maintenance dredging event	No, taken to upland site	x	x	
		E	1994	3,000	-14	Maintenance dredging event	No, taken to upland site	x	x	
	Adjacent to Slip 2	E	1994	2,000	Not specified	Retrieve spilled aggregate	Dredged material used as raw aggregate	x		
Terminal 115	1.78 - 1.95 (2 areas)	W	1993	3,000	-15	Maintenance dredging event, dolphin construction	Yes	x		92-2-01363
	1.5 - 1.9	W	2009	3,000	-15 / -17	Reconstruction of Berth 1 for Northland Services lease	No	x		SEPA DNS; creosote timber piles will be removed; Pier B will be demolished
Boyer	2.45 to 2.47	W	2004	—	—	Dock replacement	Yes, not confirmed by DMMO memo	x		Nationwide permit #3 200200607

Table 2-11 History of Private Maintenance Dredging Events in the LDW (1980 to 2008) (continued)

Project/Site Name	River Mile	River Side	Dredge Year	Volume Dredged (cy)	Pay Depth / Overdepth (ft MLLW)	Purpose	Suitable for Open-water Disposal?	Source Type		Permit
								Pre-dredge Documents[a]	Post-dredge Confirmation[b]	
Boyer	2.39 to 2.49	W	1998	8,000	-10	Maintenance dredging event	DMMUs 5, 6 suitable DMMUs 1-4 at Hurlen site	x	x	98-2-00477: permit allows dredging to -8 ft MLLW; but 1998 dredging extended to -10 ft.
Hurlen	2.64 to 2.77	W	1998	15,000	-10	Maintenance dredging event	DMMUs 1, 4 suitable DMMUs 2, 3 not suitable	x		98-2-00476
Crowley	Slip 4		1996	13,000	-15	Maintenance dredging event	DMMU 2 (3,250 cy) suitable DMMUs 1, 3, 4 (9,750 cy) not suitable	x		95-2-00537
Morton	2.86 to 2.97	W	1992	7,980	-18	Maintenance dredging event	Yes	x		OYB-2-013054, City of Seattle shoreline permit #8903261-1991
South Park Marina	3.36 to 3.44	W	1993	15,500 permitted	-8 / -9	Maintenance dredging event	1991 DMMO memo states all 8,000 cy suitable (permit allows 15,500 to be dredged)	x		OYB-2-012574
Duwamish Yacht Club	4.03 to 4.15	W	1999	24,000	-8	Maintenance dredging event	Yes	x		071-0YB-2-008104 and 071-OYB-2-012184 authorized to -7 to -11 ft MLLW at 1V:6H slope.
Delta Marine	4.17 to 4.24	W	2004	7,000	-10 / -11 in 0.89-acre area	Maintenance dredging event	Yes	x	x	NWS-200200175: periodic to -10 ft MLLW; march 2008 requested deepening of portion of area dredged in 2004 to -15 ft. NWS-2008320-NO: expansion to adjacent 0.29-acre area (boat basin), also to -5 ft; revision to allow four dredge cycles beginning in 2008 over 10 years (3,550 cy per year). Material from deepening and expansion found suitable for open water disposal under interim dioxin/furan guidelines.
			2008	11,905	-10 / -11 (dredged in January 2008) in portion of area previously dredged in 2004, -5 / -17 to deepen other area previously dredged in 2004 (2,629 cy not yet dredged); -15 / -17 to new 0.29-acre area in permit revision (expansion of boat basin; 3,905 cy not yet dredged)	Maintenance dredging, deepening, and expansion of basin	DMMO memo indicated all 11,905 cy suitable for open water disposal; permit calls for 3,550 cy per event to be dredged; recency extension memo indicates all suitable for open water disposal	x	x	
						Total for all projects	118,384 cy suitable	74%		percentage of cy suitable for open water disposal
						Total for all projects	41,797 cy not suitable	26%		percentage of cy not suitable for open water disposal

Notes:

1. See Figure 2-27 for locations of dredging events.

a. Pre-dredge documents have been reviewed. These documents include: Sampling and Analysis Plans, Suitability Determination Reports, Dredged Materials Characterization Reports, Request for Comments on Proposed Work in CERCLA Area, and Sediment Characterization Reports, and SEPA DNS of Proposed Action.

b. Post-dredge documents have been reviewed. These documents include: Remediation Reports and Dredging Summary and Analysis Reports; USACE inspection reports; recency extensions; the Port Series 2003, piers, wharves, and docks tables; and later DMMO memos or later sampling plans that document previous dredging.

— = unknown / not documented; cy= cubic yards; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; DMMO = Dredged Material Management Office; DMMU = dredged material management unit; DNS = Determination of Non-Significance; E = east; ft = feet; LDW = Lower Duwamish Waterway; MLLW = mean lower low water; SEPA = State Environmental Policy Act; USACE = United States Army Corps of Engineers; W = west

Table 2-12 Dredging Events for Contaminated Sediment Removal

Project/Site Name	River Mile	River Side	Dredging Year	Volume Dredged (cy)	Notes
Contaminated Sediment Removal from LDW					
Slip 4 EAA	2.8	E	2011	10,260	Removed sediment and bank soil. Disposed of off-site. Constructed 3.6-acre cap using clean sand mixed with granular activated carbon; completed cap construction January 30, 2012.
Duwamish/Diagonal EAA	0.4 – 0.7	E	2003	68,250	Two areas were dredged and capped in 2003-2004. An adjacent area was covered with a thin-layer cap of sand in 2005.
Norfolk EAA: Norfolk CSO/SD	4.9	E	1999	5,190	Backfill material consisted of 6,700 cy of clean sand derived from the navigational dredging of the Upper Turning Basin.
Norfolk EAA: Boeing Developmental Center South Storm Drain	4.9	E	2003	60	Sediment was removed from the 0.04-acre area adjacent to and inshore of the Norfolk CSO cap by land-based excavation. A portion of the excavation was then backfilled with clean fill.
USACE Navigation Channel Dredging	0.6 – 0.7	navigation channel	1984	1,100	Material deposited in CAD site in West Waterway, covered with capping material from Upper Turning Basin.
Slip 1	1.0	E	1974	50,000	260 gallons Aroclor® 1242 spilled in 1974 when an electric transformer was dropped and broke on the north pier of Slip 1.
Use of LDW Sediment as Capping Material in Elliott Bay					
Elliott Bay and West Waterway	n/a		1984	unknown	Sediment dredged from Upper Turning Basin used as capping material.
Pier 51, Denny Way CSO, Pier 53-55, Pier 64-65			1989 – 1994	10,000 – 22,000 per event	
Puget Sound Resources, Elliott Bay			2004	67,000	

Notes:

See Figure 2-27 for locations of dredging events listed in the table with the exception of the Slip 4 EAA dredging, which occurred in late 2011.

CAD = contained aquatic disposal; CSO/SD = combined sewer overflow / storm drain; cy = cubic yards; EAA = early action area; E = east; LDW = Lower Duwamish Waterway; n/a = not applicable; USACE = U.S. Army Corps of Engineers.

Table 2-13 Number of Monthly LDW Bridge Openings (2003 – 2006)

Year	Openings	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Monthly Average	Daily Average
Spokane Street Bridge															
2003	All motorized vessels	228	208	261	207	193	165	133	139	95	143	122	103	166	5.5
	Tugboat-escorted vessels and barges	93	83	124	106	140	112	105	113	76	109	84	79	102	3.4
	Openings within 1 hour	68	41	81	58	50	42	20	31	16	17	21	17	39	1.3
2004	All motorized vessels	121	105	133	139	138	145	164	115	112	149	152	152	135	4.5
	Tugboat-escorted vessels and barges	95	85	97	113	111	101	133	105	98	109	94	110	104	3.4
	Openings within 1 hour	16	9	18	23	35	26	40	8	16	23	37	23	23	0.8
2005	All motorized vessels	117	93	142	133	152	166	131	160	142	143	136	105	135	4.4
	Tugboat-escorted vessels and barges	80	77	115	113	112	131	104	132	115	103	107	75	105	3.5
	Openings within 1 hour	19	10	26	29	34	33	15	38	19	22	27	10	24	0.8
First Avenue Bridge															
2005	All openings	108	119	175	158	168	147	116	135	115	92	93	124	129	4.3
2006		112	83	129	145	155	142	182	146	139	125	—	—	136	4.5
Former South Park Bridge[a]															
2005	All openings	39	63	76	47	42	59	95	76	80	53	35	46	59	2.0
2006		39	42	42	82	101	88	125	98	81	59	—	—	76	2.5

Sources:

Seattle Department of Transportation (SDOT) 2006. *Spokane Street Bridge Opening Logs, 2003-2005*. Provided by Bridge/Structures Maintenance and Operations Manager. November 15, 2006.

Washington State Department of Transportation. *First Avenue Bridge Opening Logs, 2005-2006*. Provided by Bridge/Structures Maintenance & Operations Manager. December 18, 2006.

King County Department of Transportation. *South Park Bridge Opening Logs, 2005-2006*. Provided by Bridges/Structures Operations & Maintenance Manager. December 18, 2006.

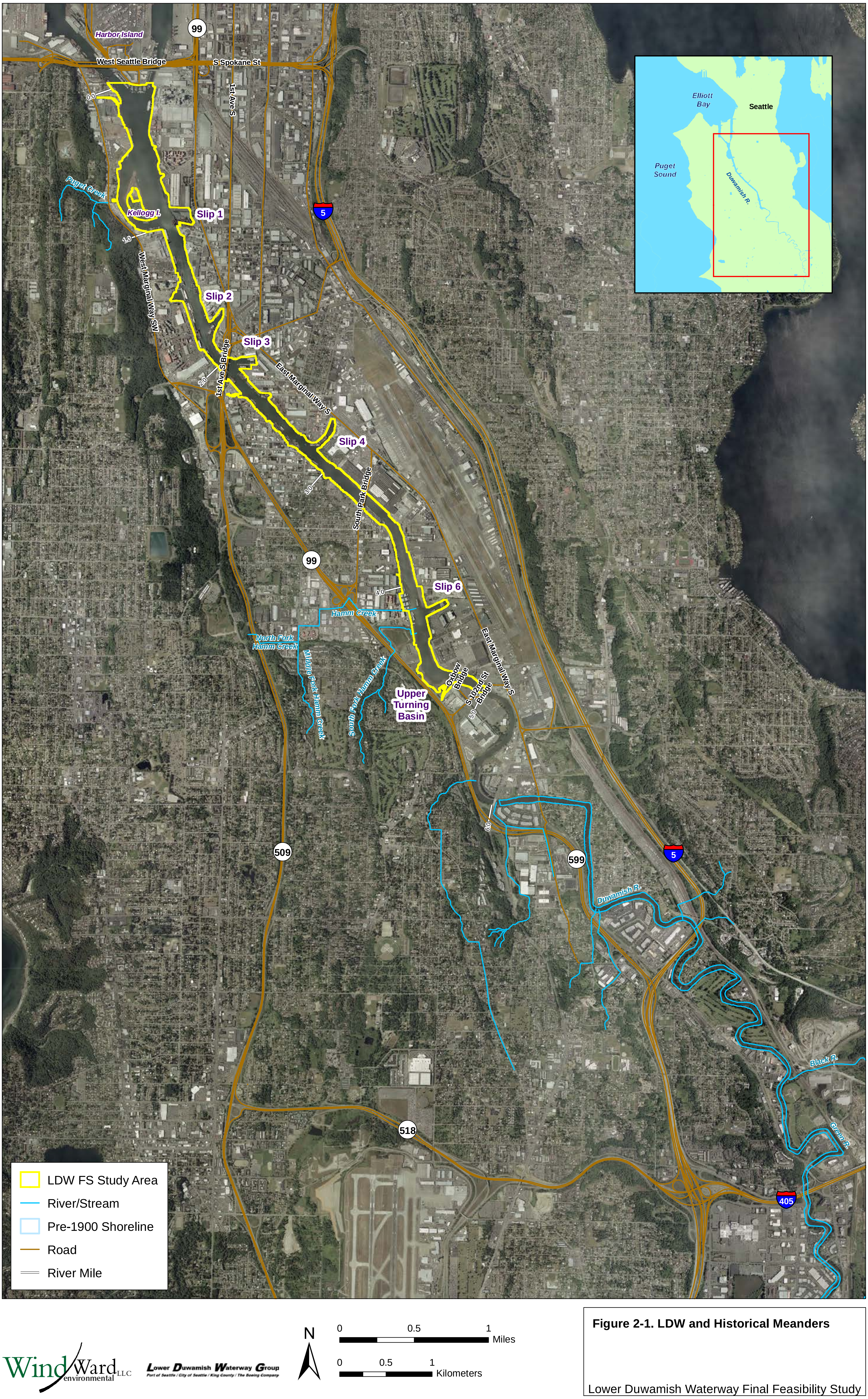
Notes:

1. During most openings, vessels moving through the opened bridge include 1 large vessel and 1 to 3 tugs.

a. This bridge was closed and demolished in 2010. A new bridge is under construction, just downstream of the former bridge location, with completion scheduled for fall of 2013.

— = data not available at time it was requested.

LDW = Lower Duwamish Waterway

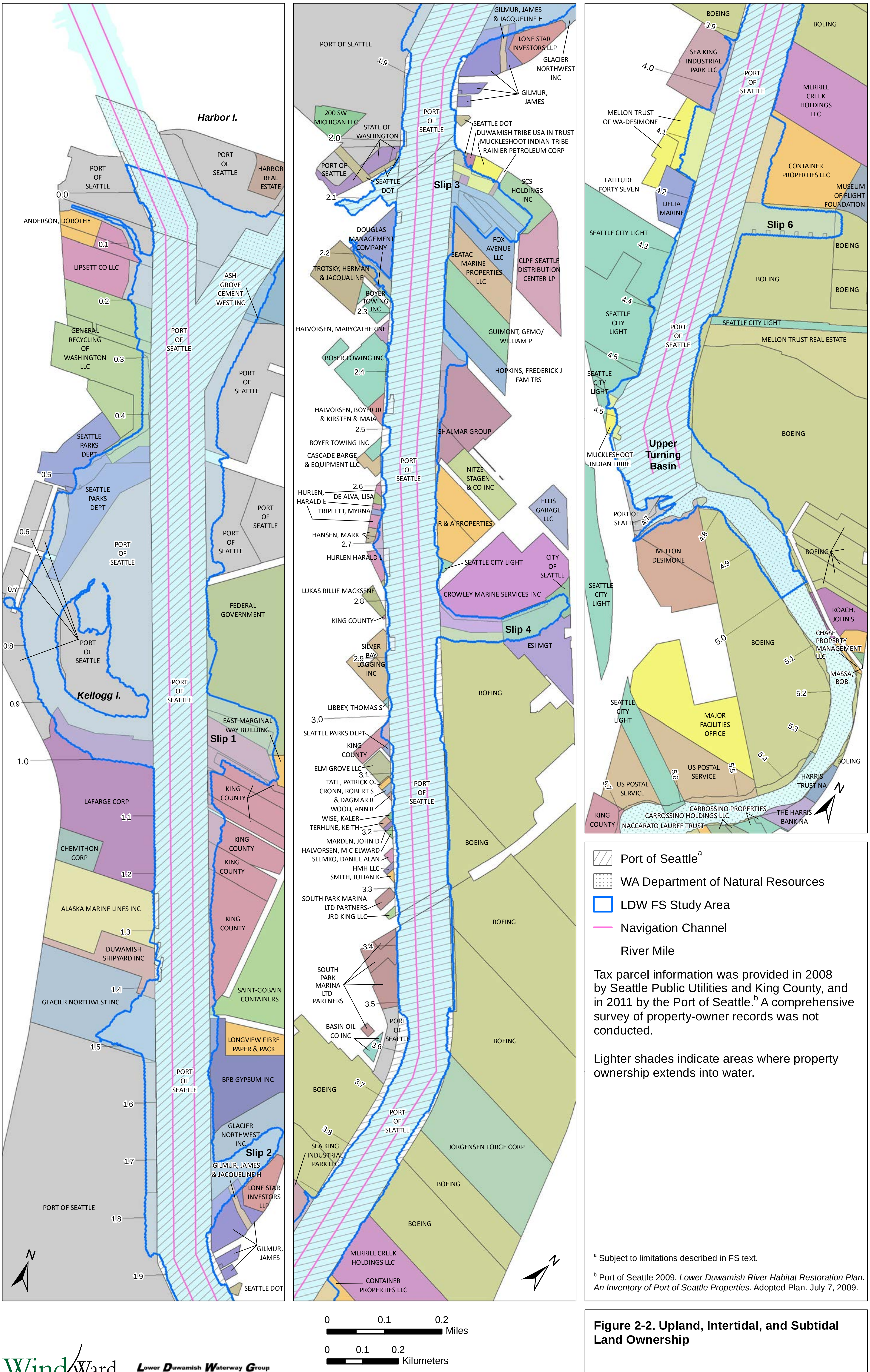


Prepared by inmann, 10/31/2012; L:\Lower Duwamish FS\FS Final_GIS\Oct2012\2012-10-15 LDW FS WW GIS Maps and Data\Fig 2-01 3091 LDW system and historical meanders1.mxd

Figure 2-1. LDW and Historical Meanders

Lower Duwamish Waterway Final Feasibility Study

Photo source: USGS High Resolution Orthoimage, Seattle/Tacoma WA, 1 m resolution. Photo date 06/11/2002.



Tax parcel information was provided in 2008 by Seattle Public Utilities and King County, and in 2011 by the Port of Seattle.[b] A comprehensive survey of property-owner records was not conducted.

Lighter shades indicate areas where property ownership extends into water.

Scale is the same for each inset map

[a] Subject to limitations described in FS text.

[b] Port of Seattle 2009. *Lower Duwamish River Habitat Restoration Plan. An Inventory of Port of Seattle Properties*. Adopted Plan. July 7, 2009.

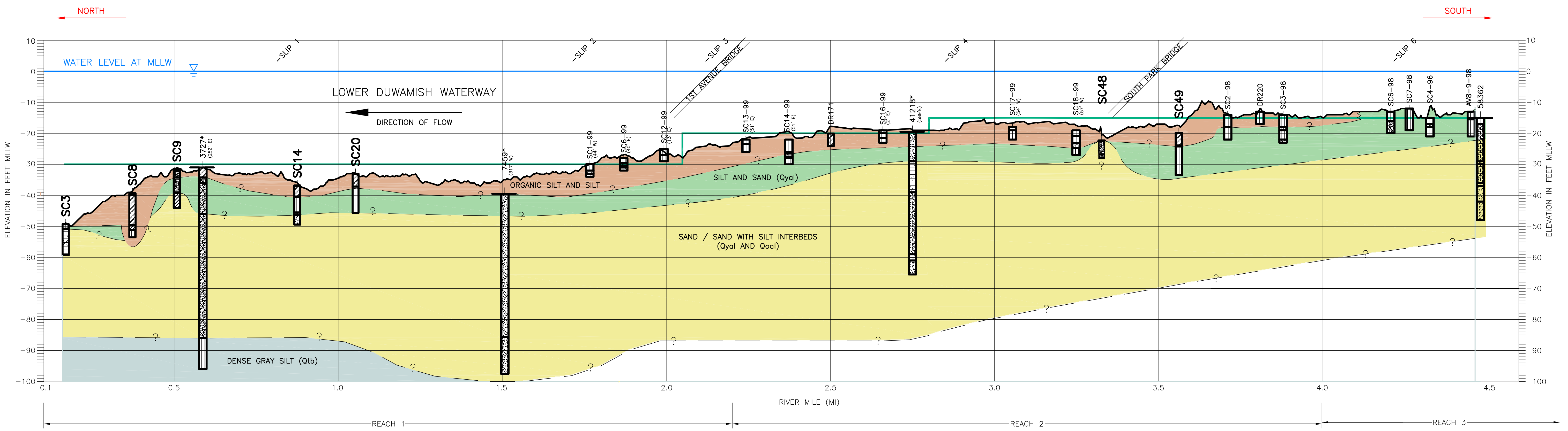
Figure 2-2. Upland, Intertidal, and Subtidal Land Ownership

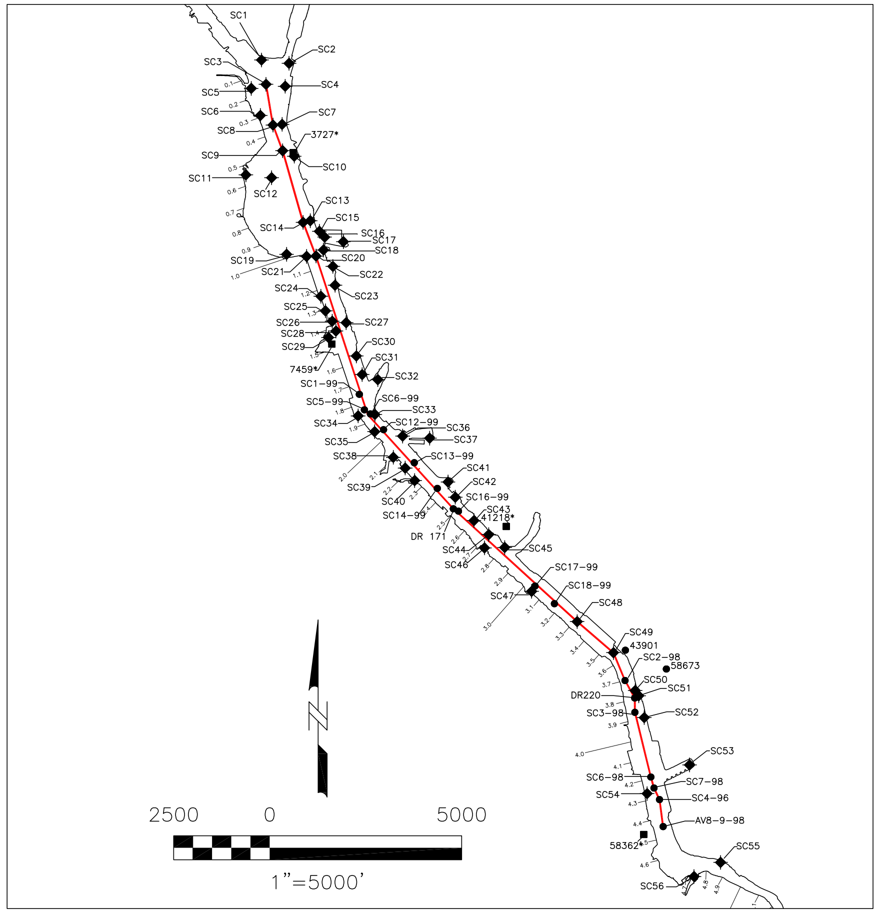
Lower Duwamish Waterway Final Feasibility Study

Prepared by inmann, 10/31/2012; L:\Lower Duwamish FS\FS Final_GIS\Oct2012\2012-10-15 LDW FS WW GIS Maps and Data\Fig 2-02 2851 Land and water ownership1.mxd

Windward environmental LLC

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company





LEGEND

DR−171 ● Historical Subsurface Core

SC4−96 = PSSDA96 study
SC2−98 = PSDDA98 study
SC6−99 = PSDDA99 study
DR171 = EPASI study

3727* ■ Upland Core

7459 = Hart Crowser 1979 study
41218 = Yonemitsu Geological Services 1979 study
3727 = Dames and Moore 1988 study
58362 = Seattle Public Utilities (CPT−D77_01) 1985 study

SC48 ◆ 2006 Subsurface Core

━━ Authorized navigation depth (ft MLLW)

━━ Mid−channel mudline elevation (based on 2003 bathymetric survey, ft MLLW; Windward and DEA 2004)

━━ Water level at MLLW (ft)

— — Top of projected core not shown

KEY

SC14−99 (51' E) — Core Name (Distance from section to Core)

—Top of Core

—Observed Contacts

—Bottom of Core

LITHOLOGY

- ▨ Clay/Silt
- ▨ Organic silt
- ◫ Silt
- ▩ Sand with silt
- ☰ Sand with silt interbeds
- ▩ Sand
- ⛶ Gravel, sandy gravel

STRATIGRAPHY**

- 🟫 RECENT
- 🟩 UPPER ALLUVIUM/TRANSITION
- 🟨 LOWER ALLUVIUM
- ⬜ DENSE POST−GLACIAL AND GLACIAL UNIT

Qtb = TRANSITIONAL SILTS
Qyal = YOUNGER ALLUVIUM
Qoal = OLDER ALLUVIUM

800 0 1600

HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION = 50:1

NOTES

1) MLLW − mean lower low water

2) 2006 Phase 2 cores (SC3, SC8, SC9, SC14, SC20, SC48, SC49) are labeled with bold font in cross section.

3) AV8−9−98 is an average of Cores 8 and 9 from PSDDA (1998).

4) Upland cores from GeoMap NW, Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php

5) Cross sections represent regional geology. See core logs in the Subsurface Sediment Data Report (Windward 2007) for detailed stratigraphy.

* Upland cores projected into navigation channel. Lower portions of upland cores used to bound deeper sediment units.

** Stratigraphy terminology is used in Subsurface Data Report (Windward and RETEC 2007) and Sediment Transport Analysis Report (Windward and QEA 2008).

AECOM

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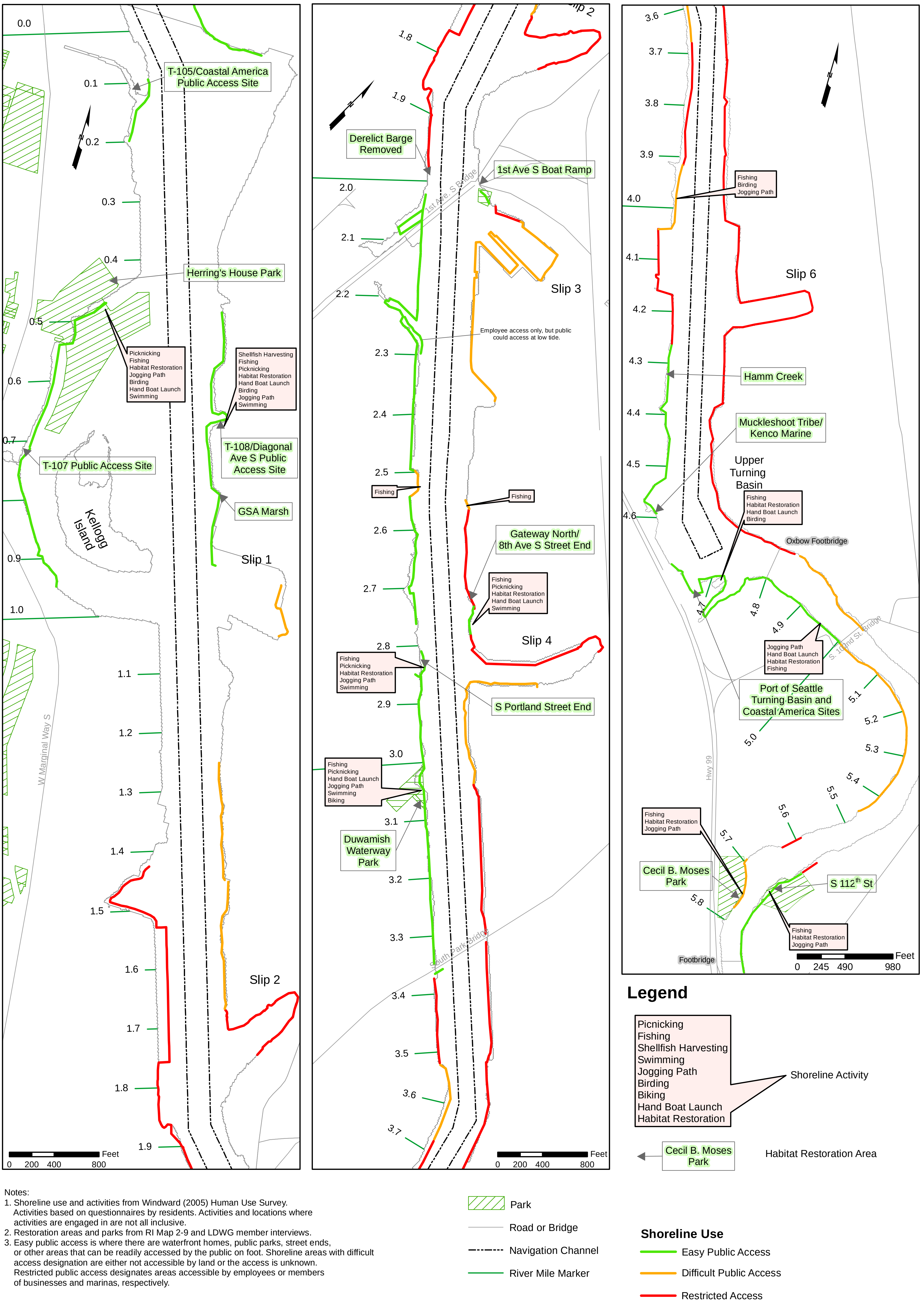
LOWER DUWAMISH WATERWAY
FINAL FEASIBILITY STUDY
60150279-14.34

NAVIGATION CHANNEL
LONGITUDINAL CROSS SECTION

DATE: 10/31/12 | DRWN: E.M./MO/SEA

FIGURE 2-3

File: G:\PROJECTS\CADD\Lower Duwamish\X-SECTS 6-17-08\18220-LONG(c).dwg Layout: FIG User: oliveriam Plotted: Nov 12, 2012 - 4:34pm Xref's:



Notes:
1. Shoreline use and activities from Windward (2005) Human Use Survey. Activities based on questionnaires by residents. Activities and locations where activities are engaged in are not all inclusive.
2. Restoration areas and parks from RI Map 2-9 and LDWG member interviews.
3. Easy public access is where there are waterfront homes, public parks, street ends, or other areas that can be readily accessed by the public on foot. Shoreline areas with difficult access designation are either not accessible by land or the access is unknown. Restricted public access designates areas accessible by employees or members of businesses and marinas, respectively.

L:\Lower Duwamish FS\IFS_Final_GISOct2012\FS_GIS_MXDs_Oct12\Section 2\Figure2-4ParksRestorationShoreAccess.mxd

AECOM

Lower Duwamish Waterway Group
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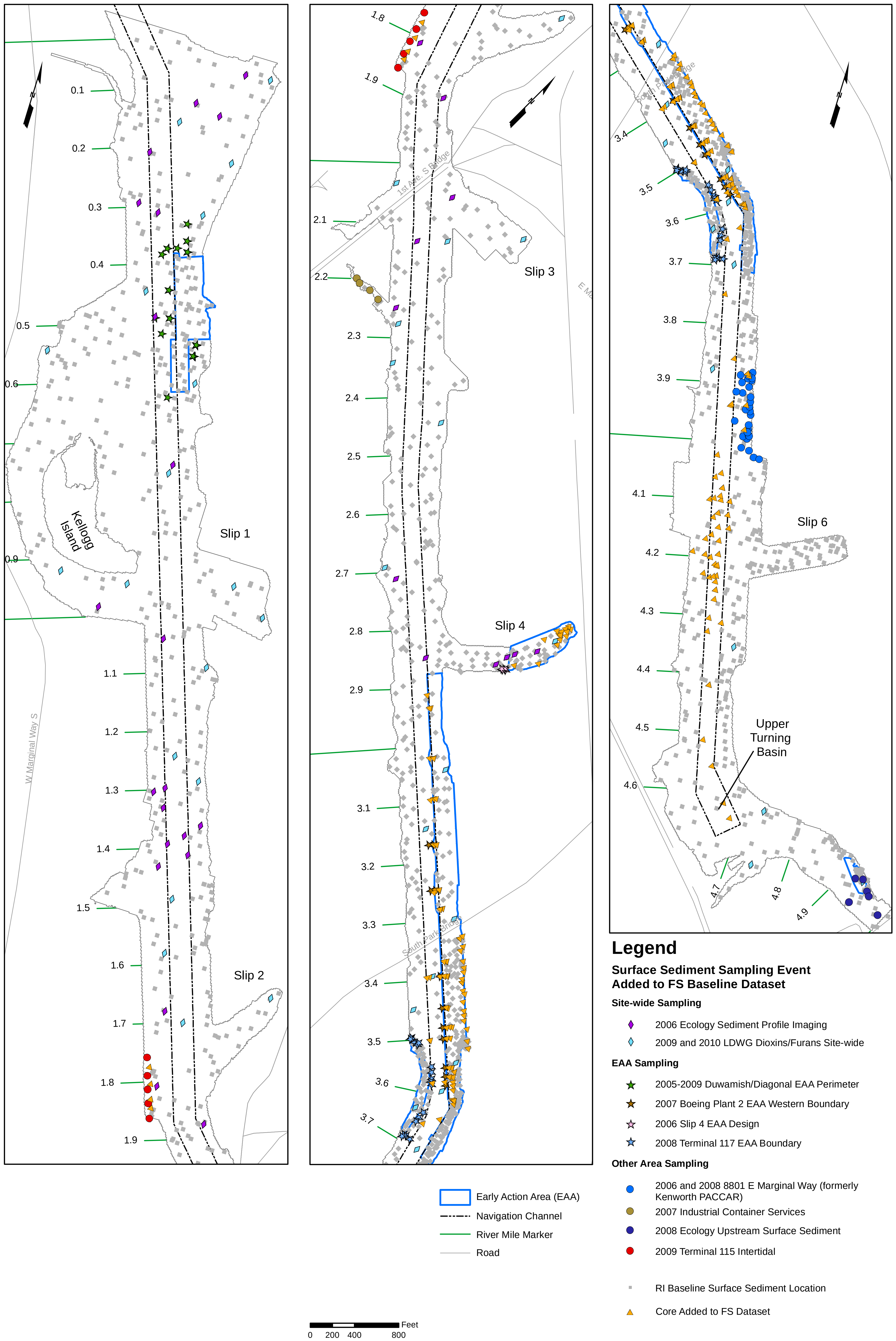
Lower Duwamish Waterway
Final Feasibility Study
60150279-14.34

DATE: 10/31/12 | DWRN: MVI/sea | Revision: 1

Habitat Restoration Areas, Parks, and Shoreline Access

FIGURE 2-4



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60150279-14.34

Surface Sediment Sampling Locations Added Since October 2006 to Generate FS Baseline Dataset

DATE: 10/31/12	DWRN: mvi/SEA	Revision: 0		**FIGURE 2-5**

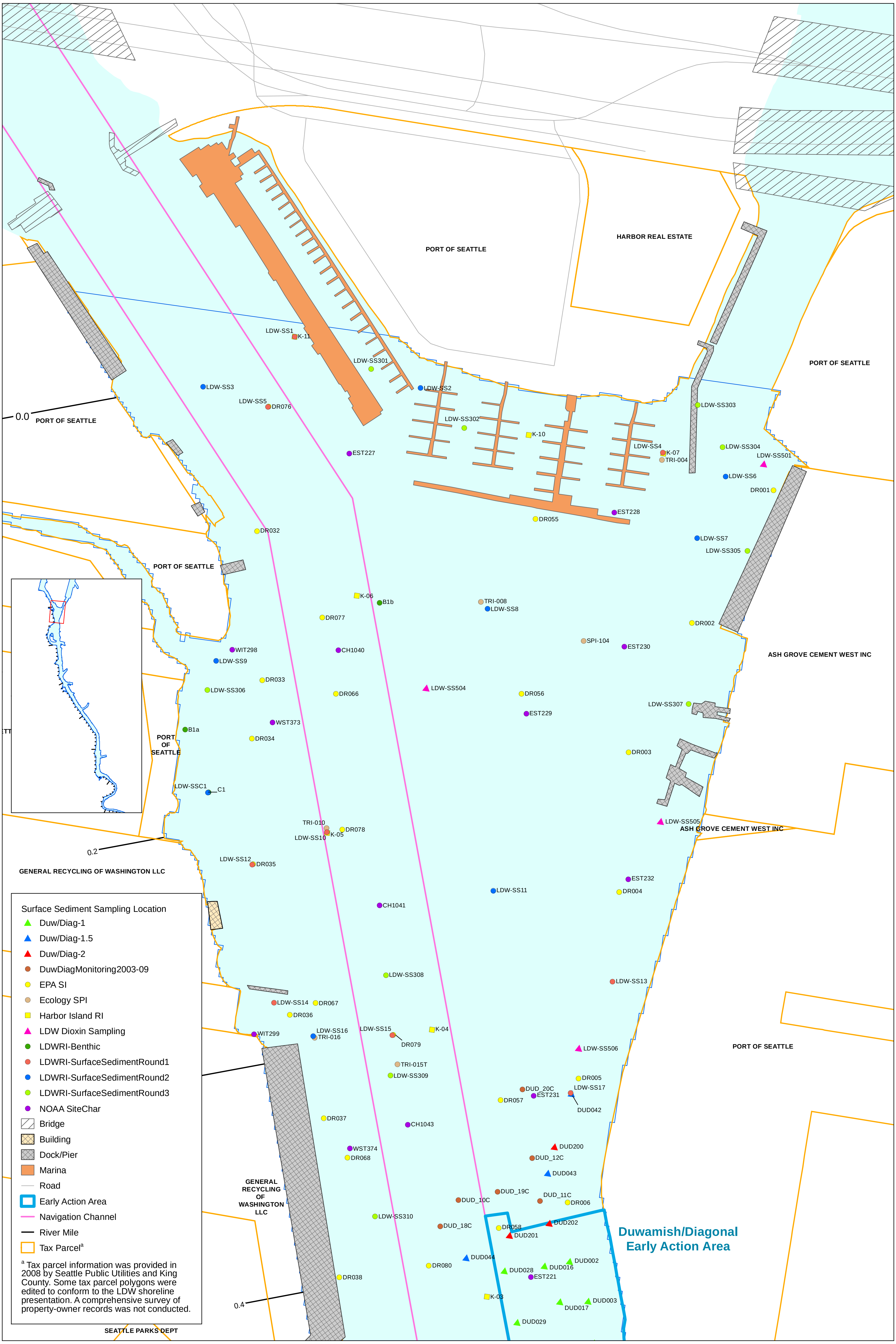

Figure 2-6a. Surface Sediment Sampling Locations, RM 0.0 to RM 0.4

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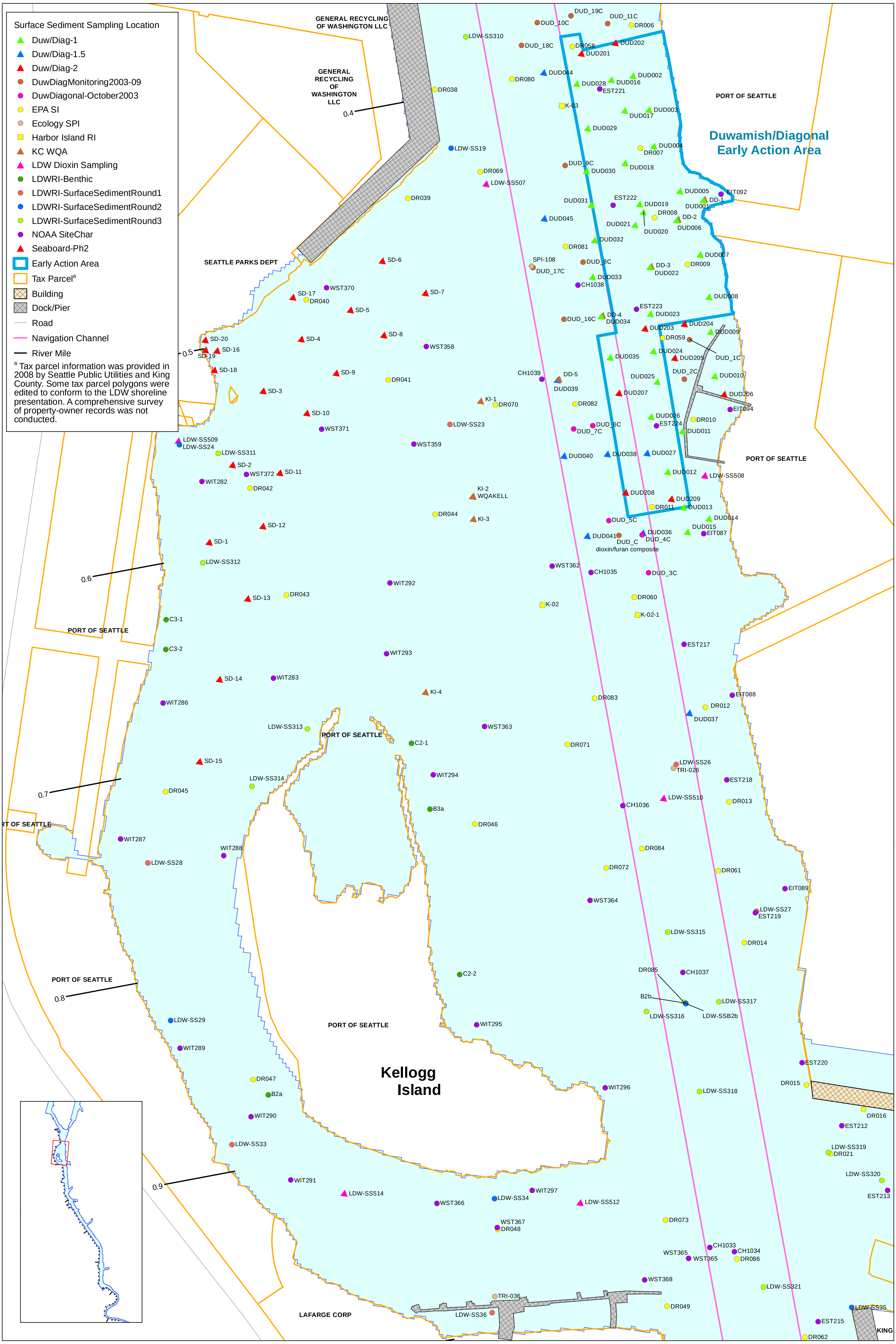

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Figure 2-6b. Surface Sediment Sampling Locations, RM 0.4 to RM 0.9

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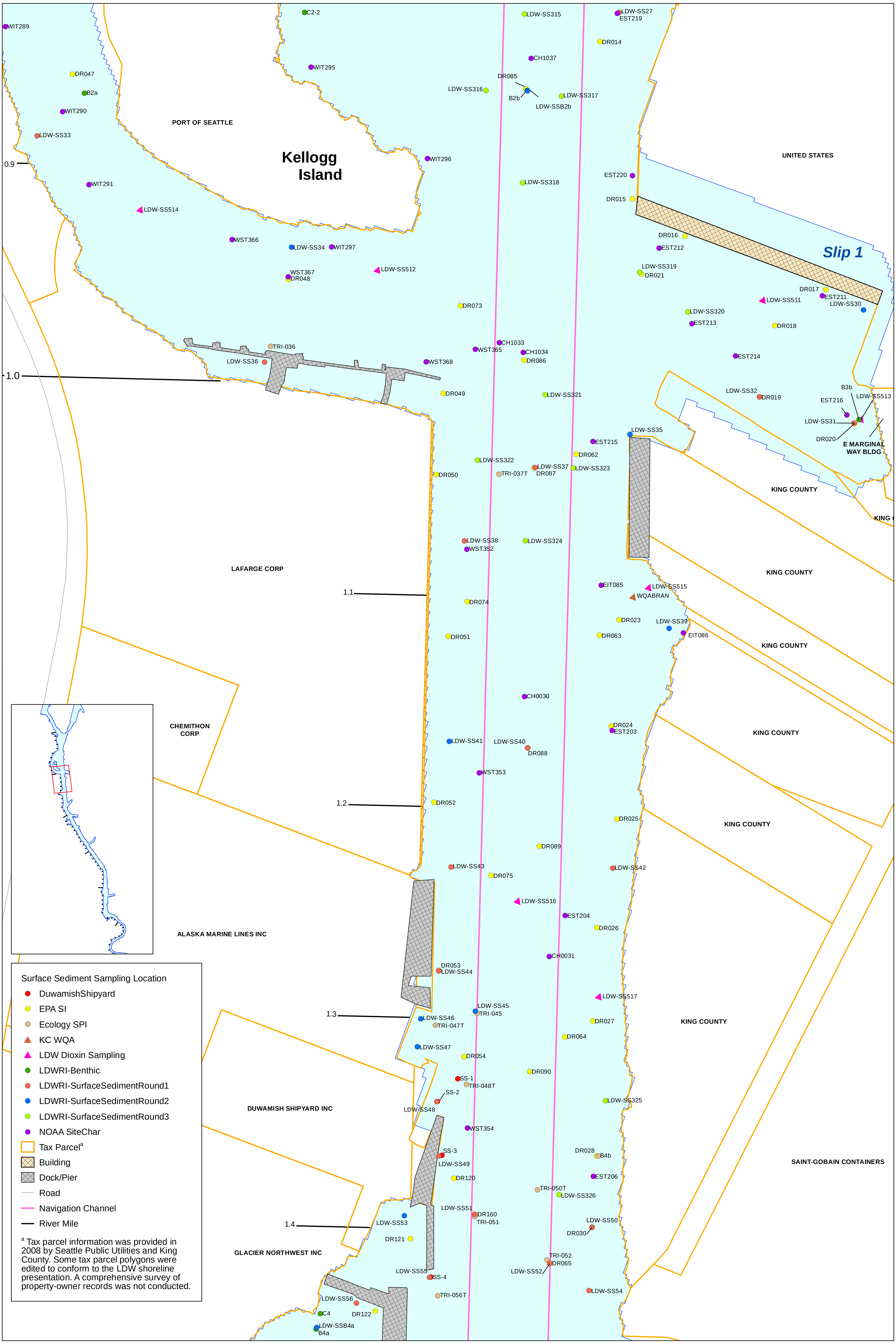

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Figure 2-6c. Surface Sediment Sampling Locations, RM 0.9 to RM 1.4

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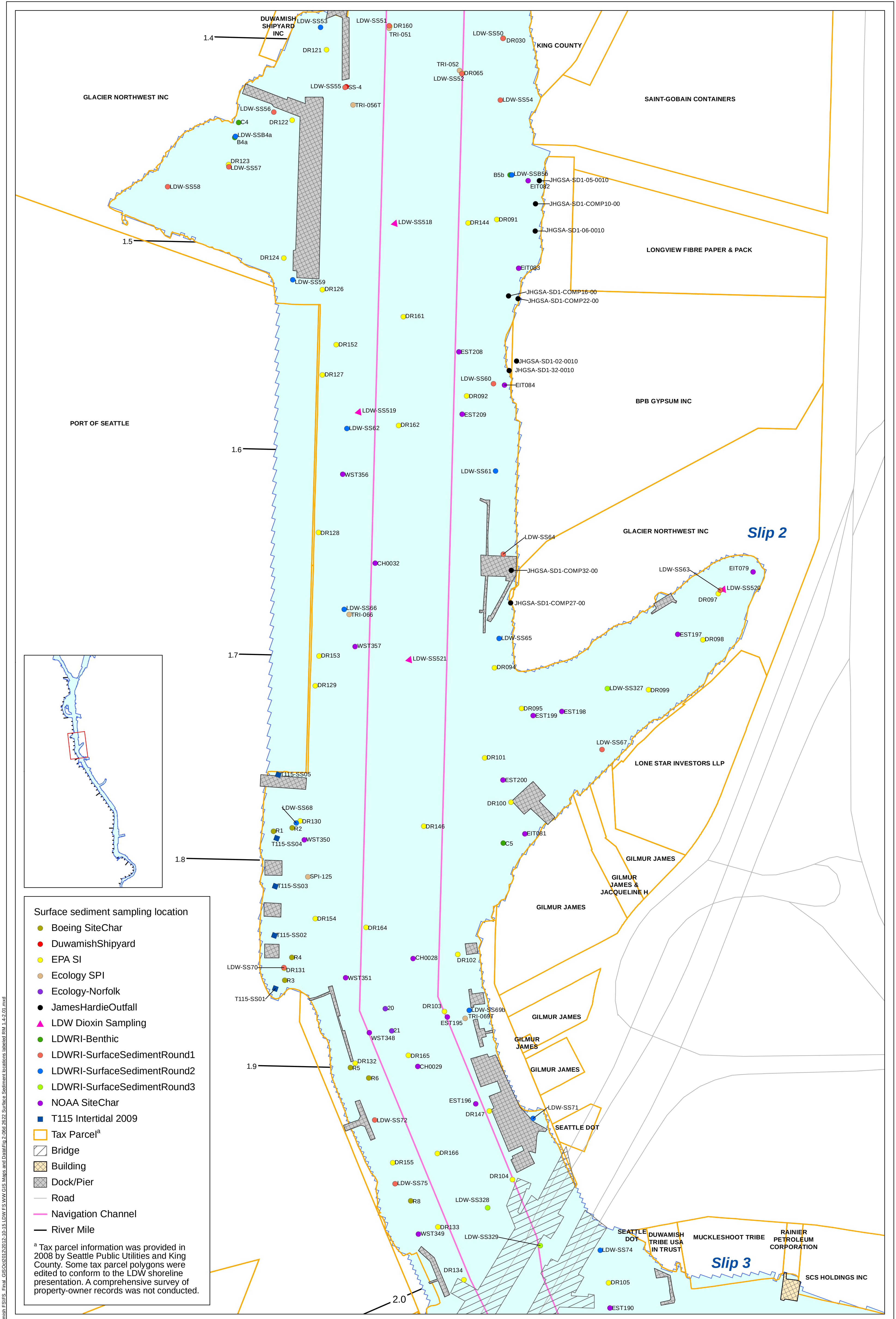

Figure 2-6d. Surface Sediment Sampling Locations, RM 1.4 to RM 2.0

Lower Duwamish Waterway Final Feasibility Study

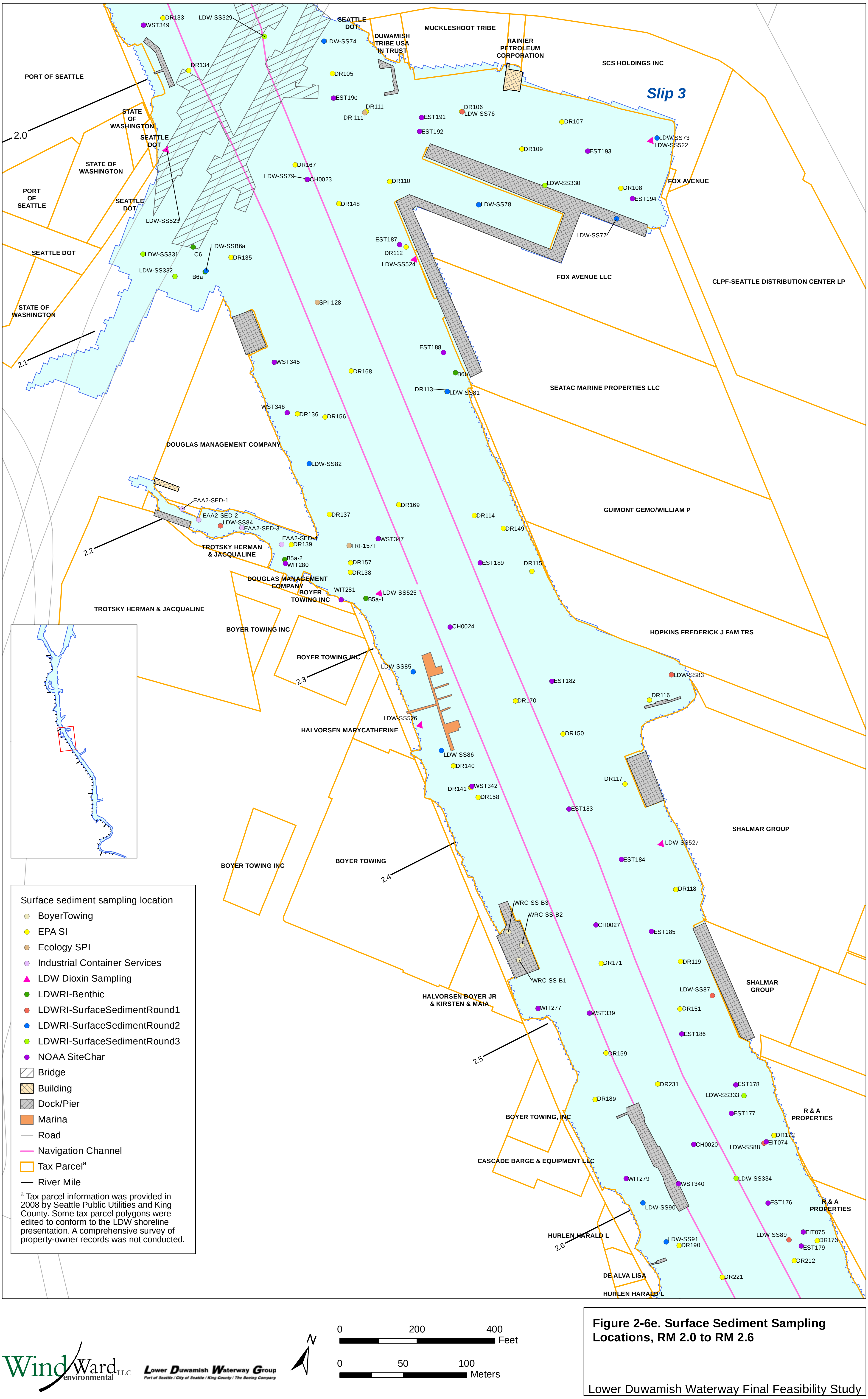

Figure 2-6e. Surface Sediment Sampling Locations, RM 2.0 to RM 2.6

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dyn type="user"/>, 10/31/2012; L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\2012-10-15 LDW FS WW GIS Maps and Data\Fig 2-06e 2623 Surface Sediment locations labeled RM 2.0-2.61.mxd

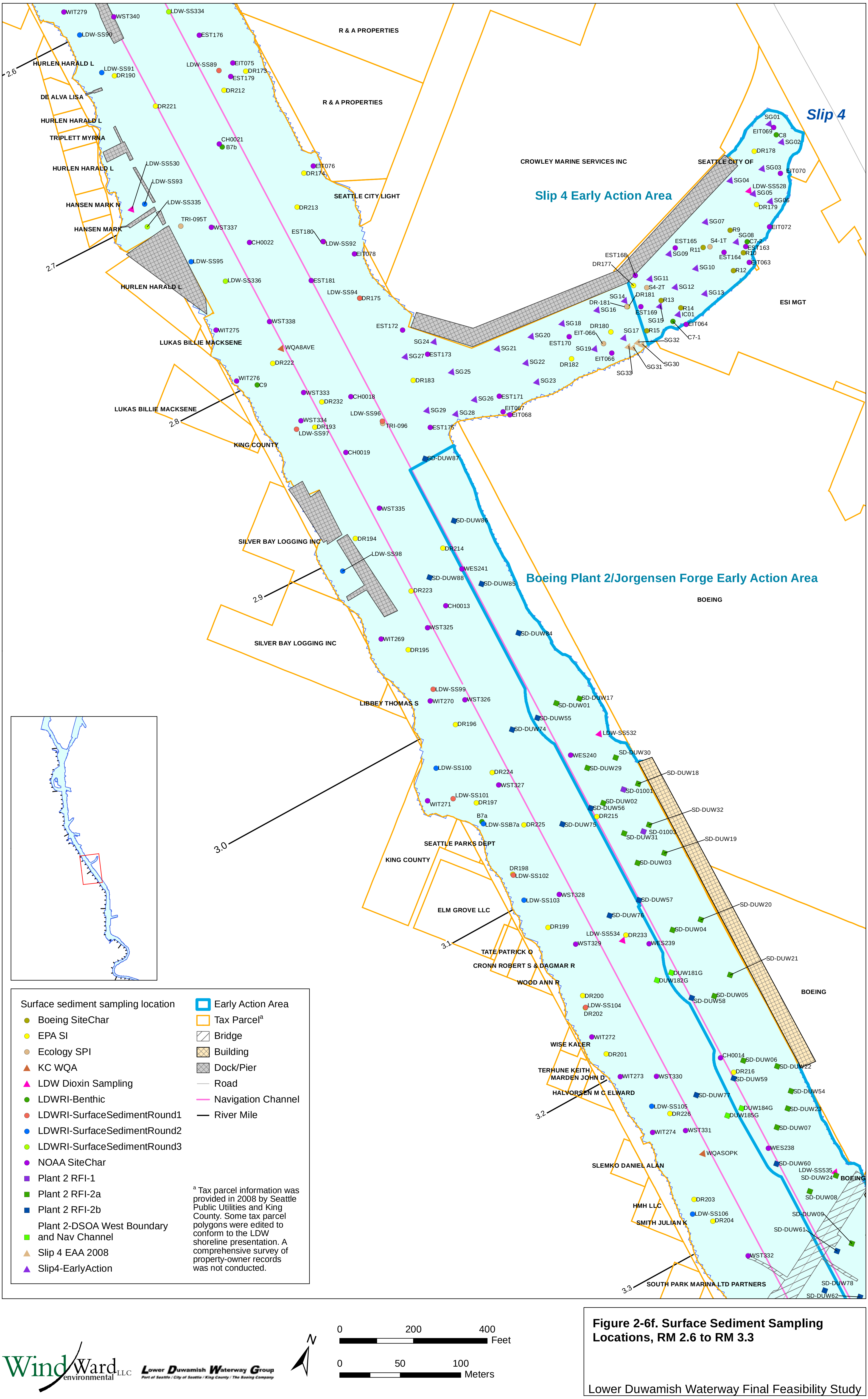

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Figure 2-6f. Surface Sediment Sampling Locations, RM 2.6 to RM 3.3

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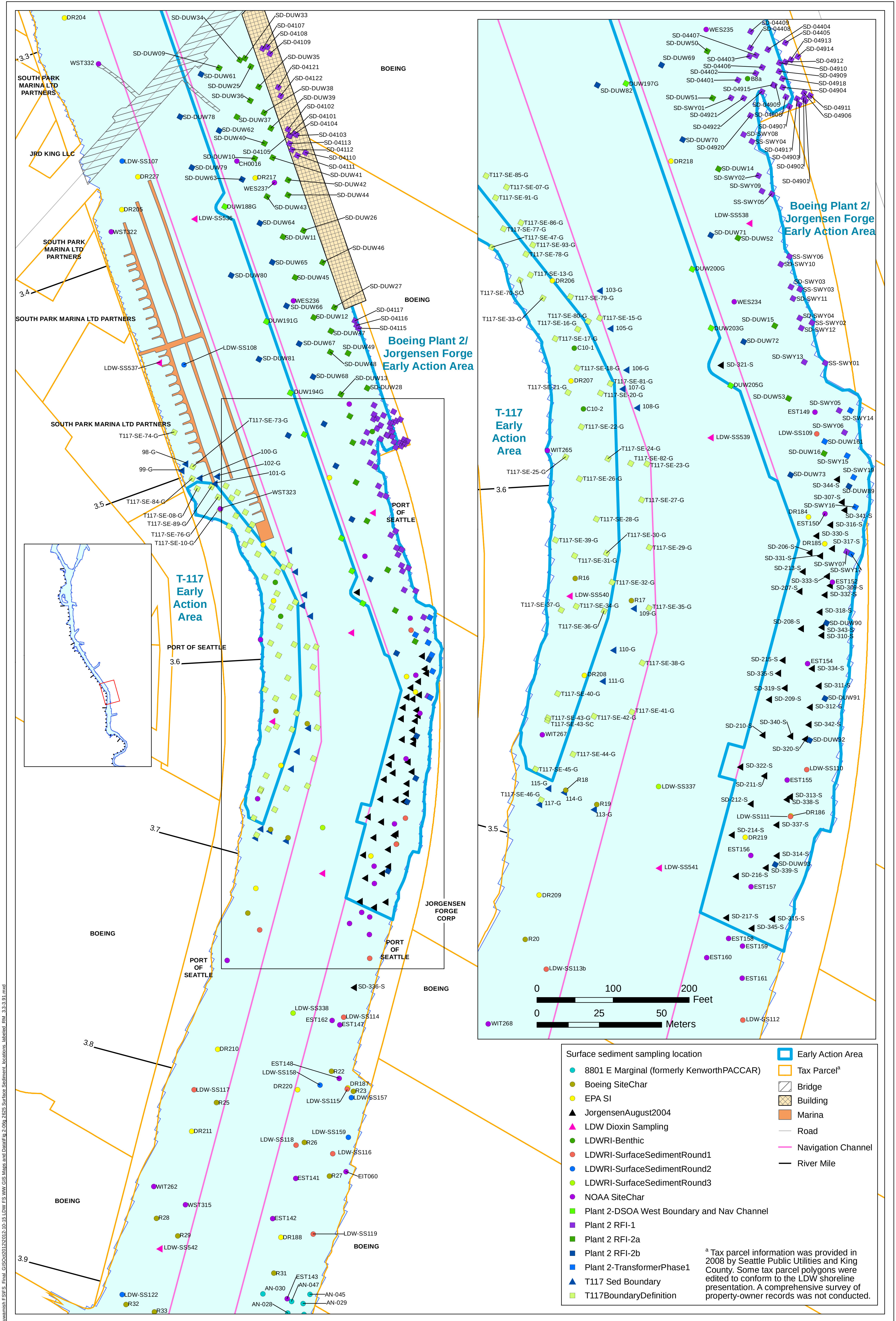
dyn type="user"/>, 10/31/2012; L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\2012-10-15 LDW FS WW GIS Maps and Data\Fig 2-06f 2624 Surface Sediment locations labeled RM 2.6-3.31.mxd



[a] Tax parcel information was provided in 2008 by Seattle Public Utilities and King County. Some tax parcel polygons were edited to conform to the LDW shoreline presentation. A comprehensive survey of property-owner records was not conducted.

0 200 400 Feet
0 50 100 Meters

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Figure 2-6g. Surface Sediment Sampling Locations, RM 3.3 to RM 3.9

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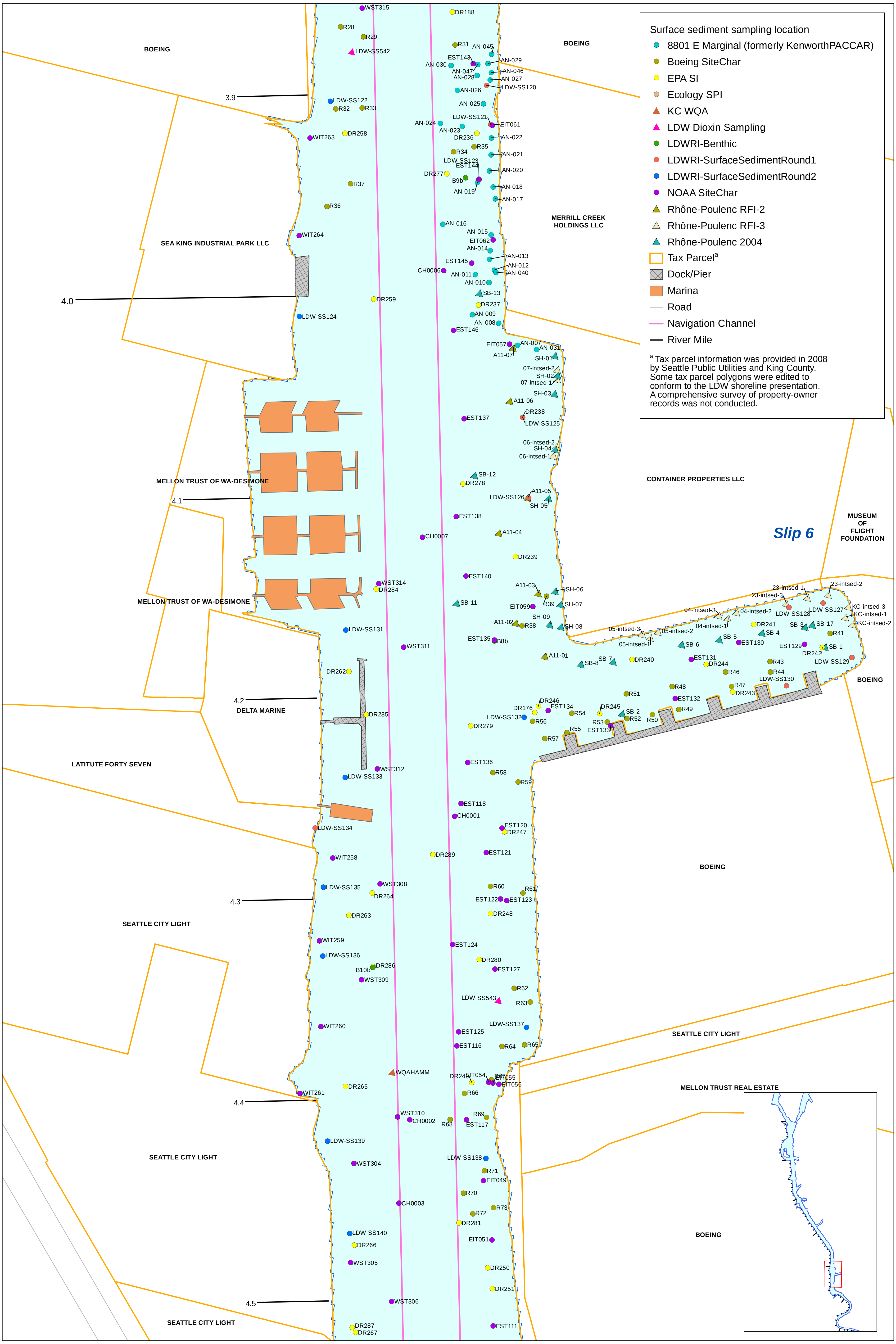

Figure 2-6h. Surface Sediment Sampling Locations, RM 3.9 to RM 4.5

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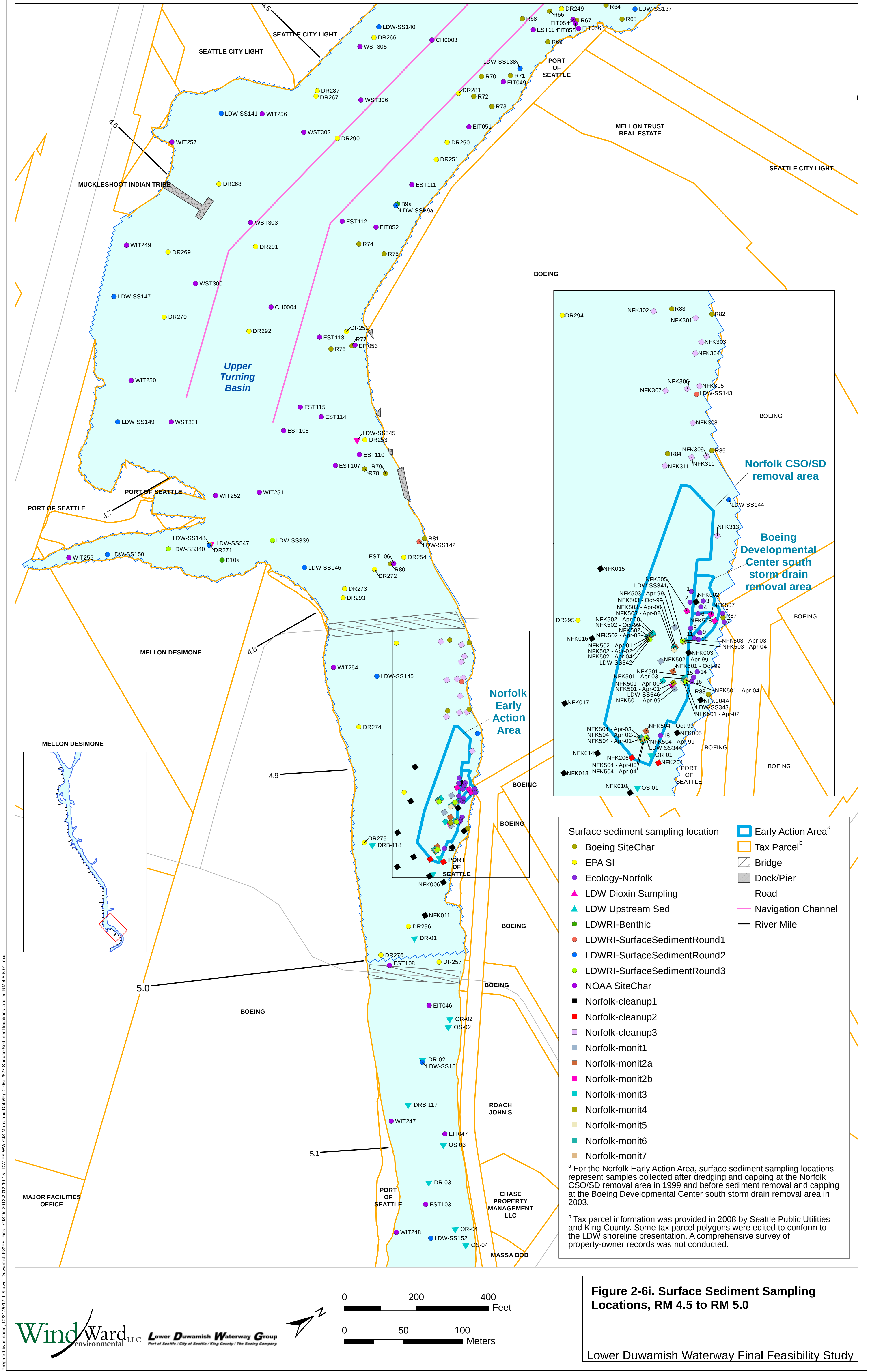

[a] For the Norfolk Early Action Area, surface sediment sampling locations represent samples collected after dredging and capping at the Norfolk CSO/SD removal area in 1999 and before sediment removal and capping at the Boeing Developmental Center south storm drain removal area in 2003.

[b] Tax parcel information was provided in 2008 by Seattle Public Utilities and King County. Some tax parcel polygons were edited to conform to the LDW shoreline presentation. A comprehensive survey of property-owner records was not conducted.

Figure 2-6i. Surface Sediment Sampling Locations, RM 4.5 to RM 5.0

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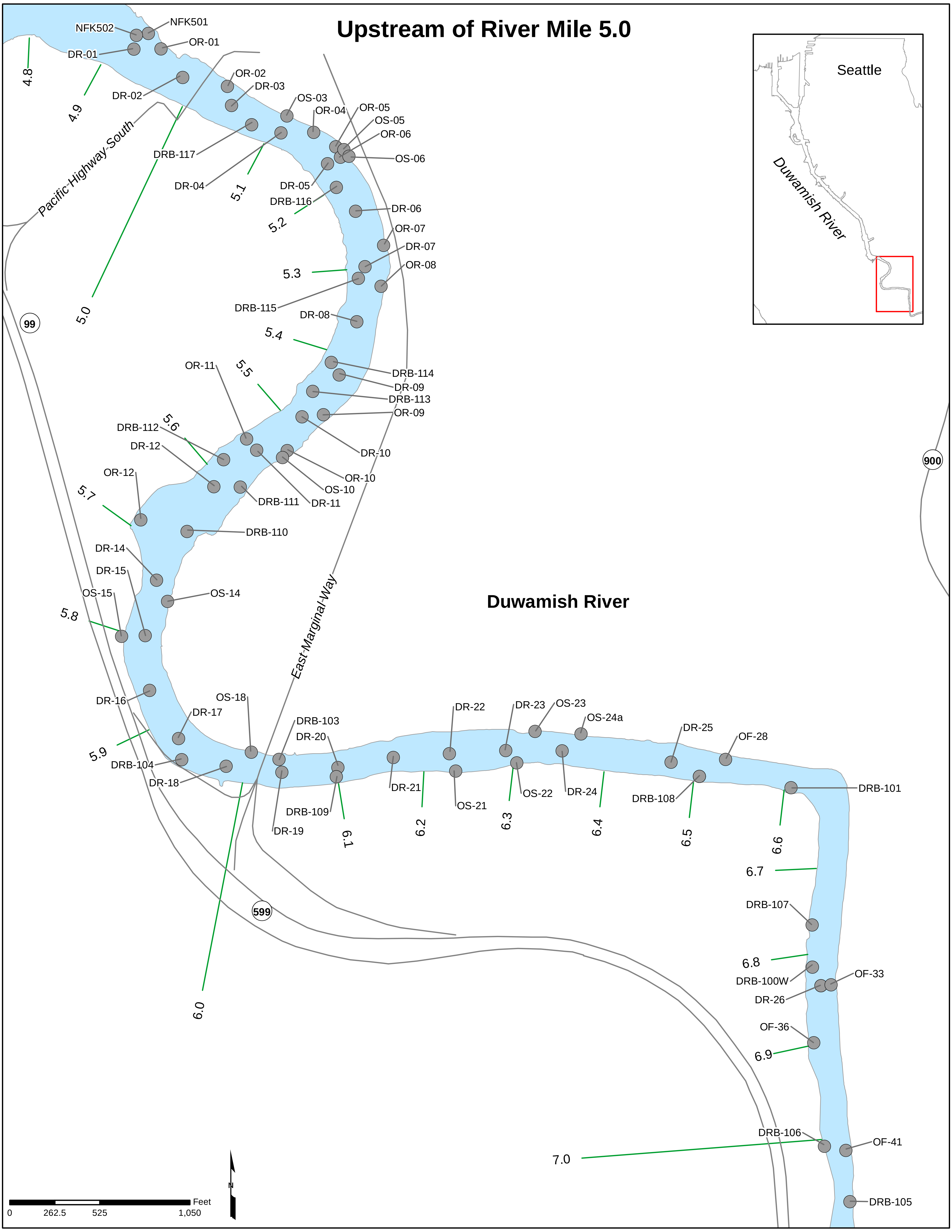

Notes:
1. Surface sediment samples from RM 4.9 to 6.5 are from 2008 Ecology study. DR = center channel samples,
OS = samples near the discharge points of outfalls, OR = samples within the Duwamish River approximately 15 meters downstream of outfall discharge points, DRB = bank samples that appear to be depositional environments,
OF = bank samples at discharge points of selected newly identified outfalls upstream of RM 6.5,
NFK = samples near the Norfolk combined sewer overflow.
2. Surface sediment samples collected at depths between 0 and 10 cm.

Legend

Upstream Surface Sediment Sample Location

● Ecology 2008 Study

— River Mile Marker

— State Highway

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Ecology 2008 Upstream Surface Sediment Sampling Locations

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FIGURE 2-7

L:\Lower Duwamish FS\IFS_Final_GISOct2012\FS_GIS_MXDs_Oct12\Section 2\Figure2-7Ecologysamplelocationsupstreamof RM4.0.mxd

Figure 2-8a LDW Conceptual Site Model for Reach 1

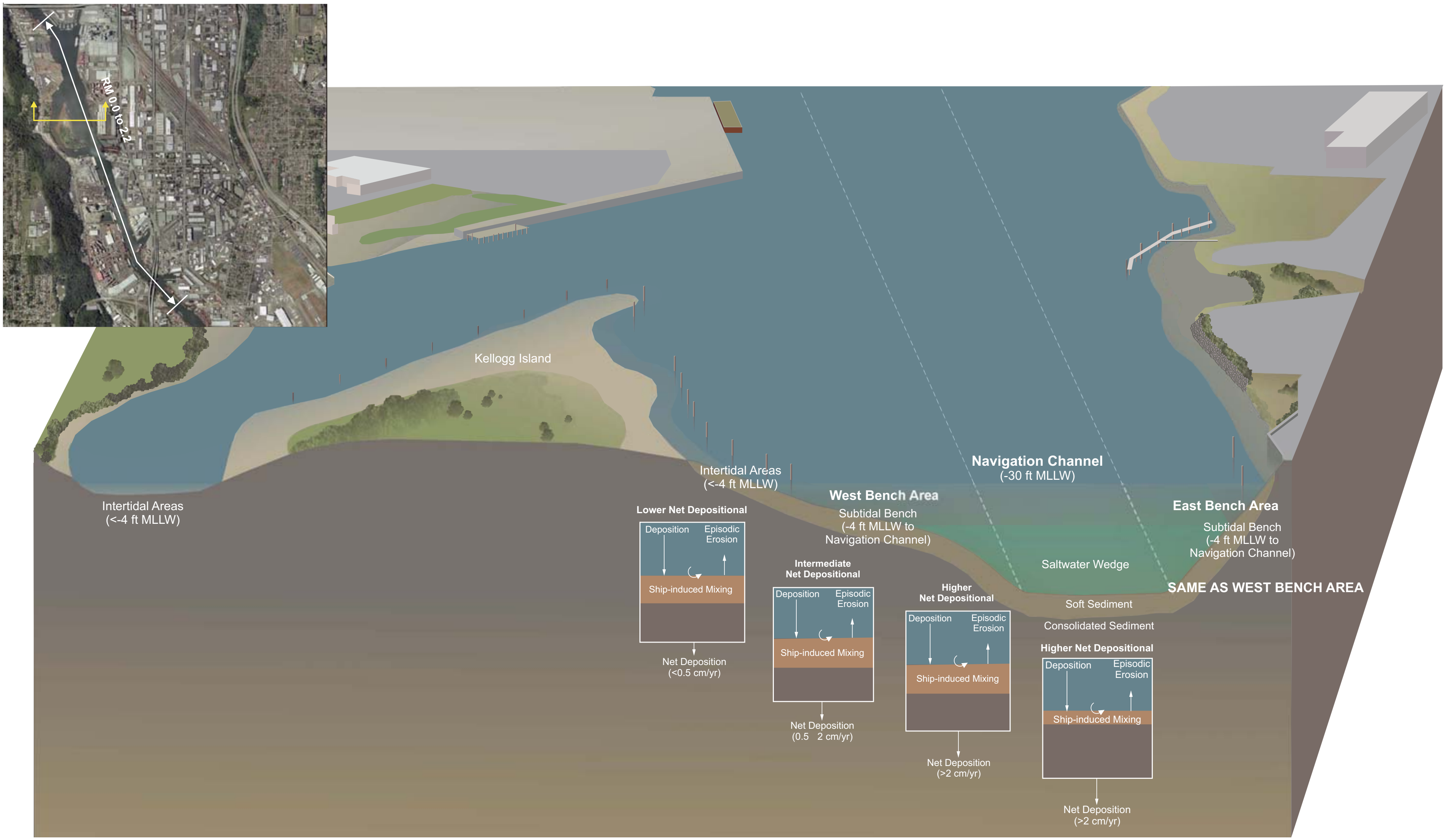


Figure 2-8b LDW Conceptual Site Model for Reach 2

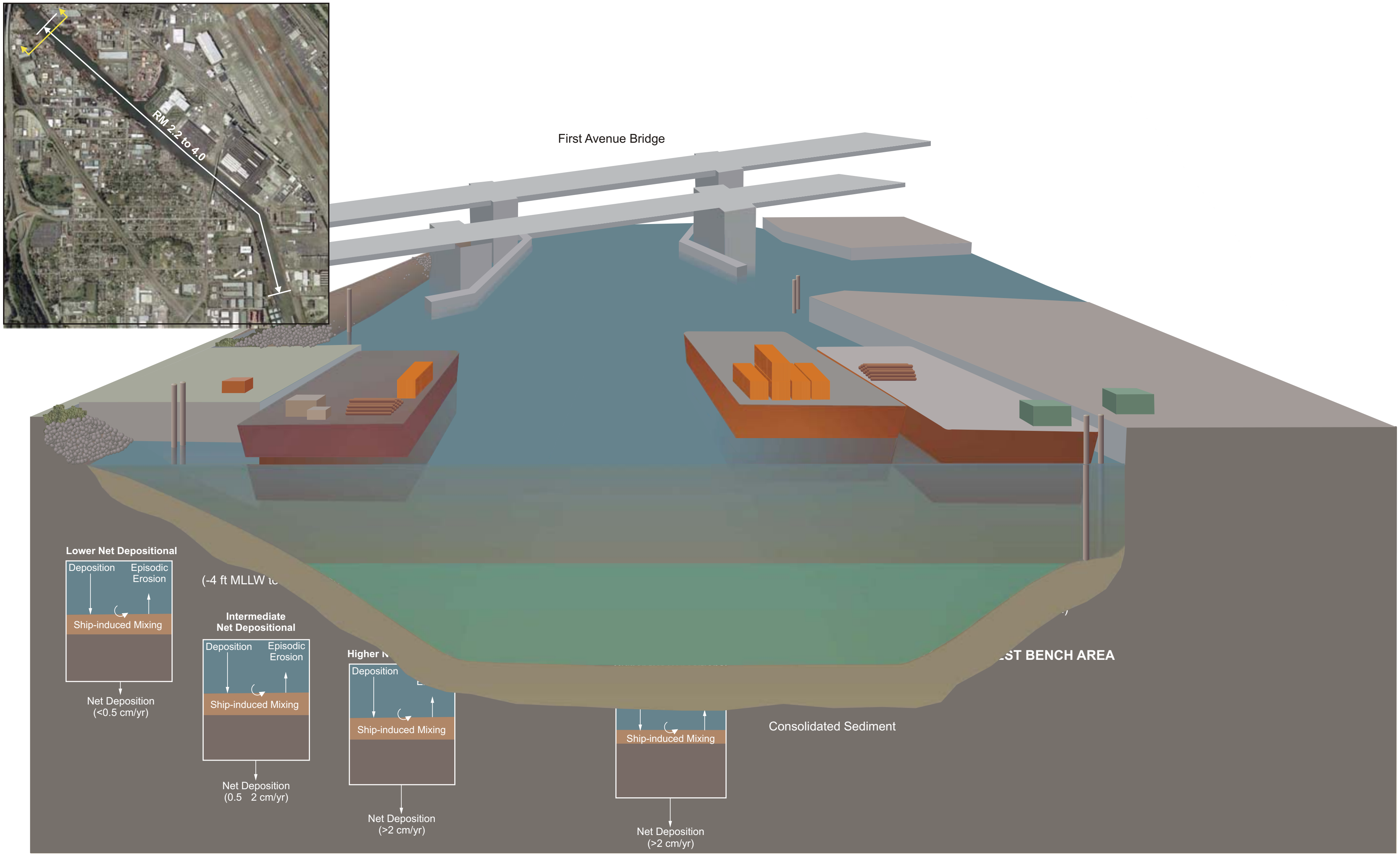
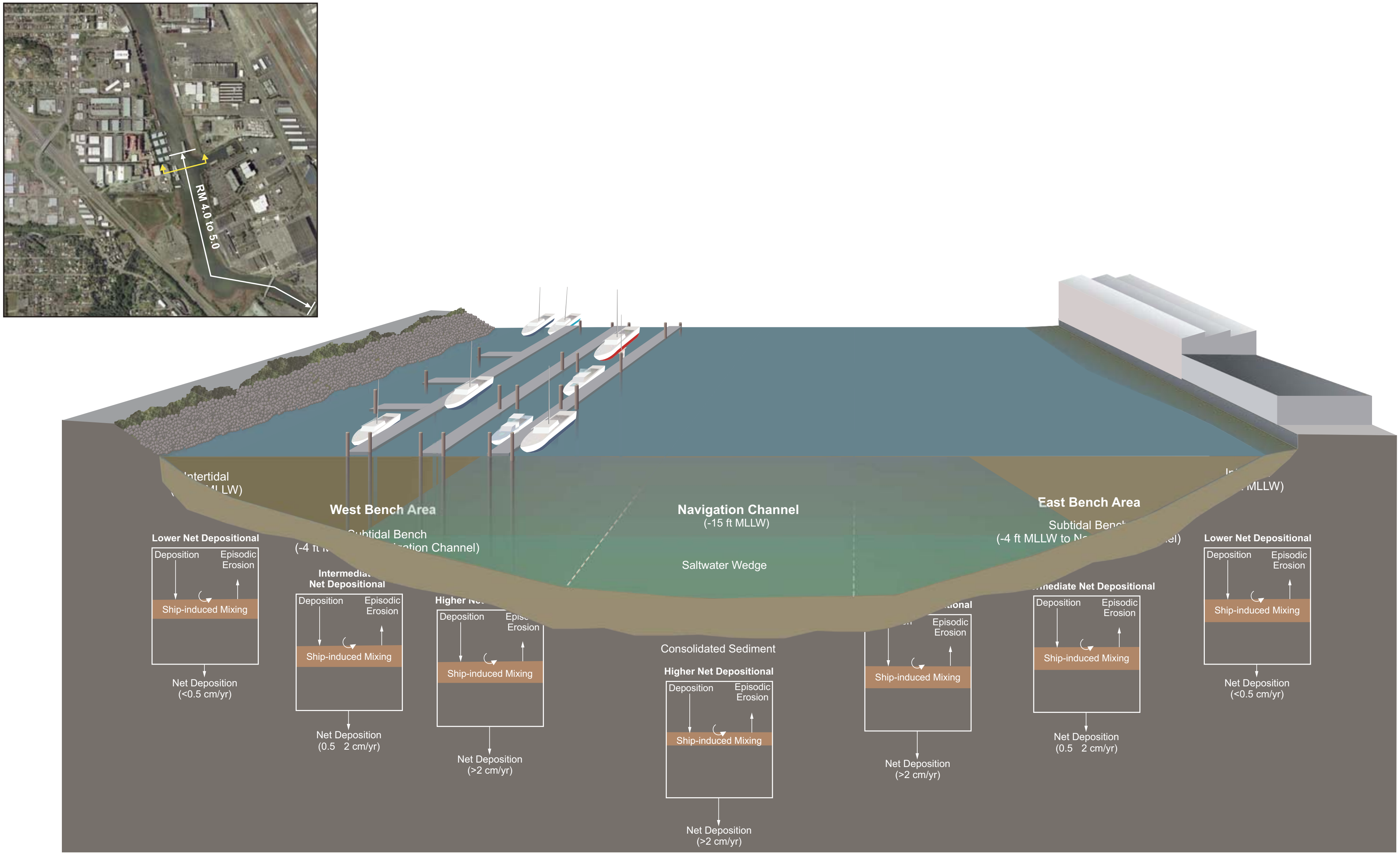
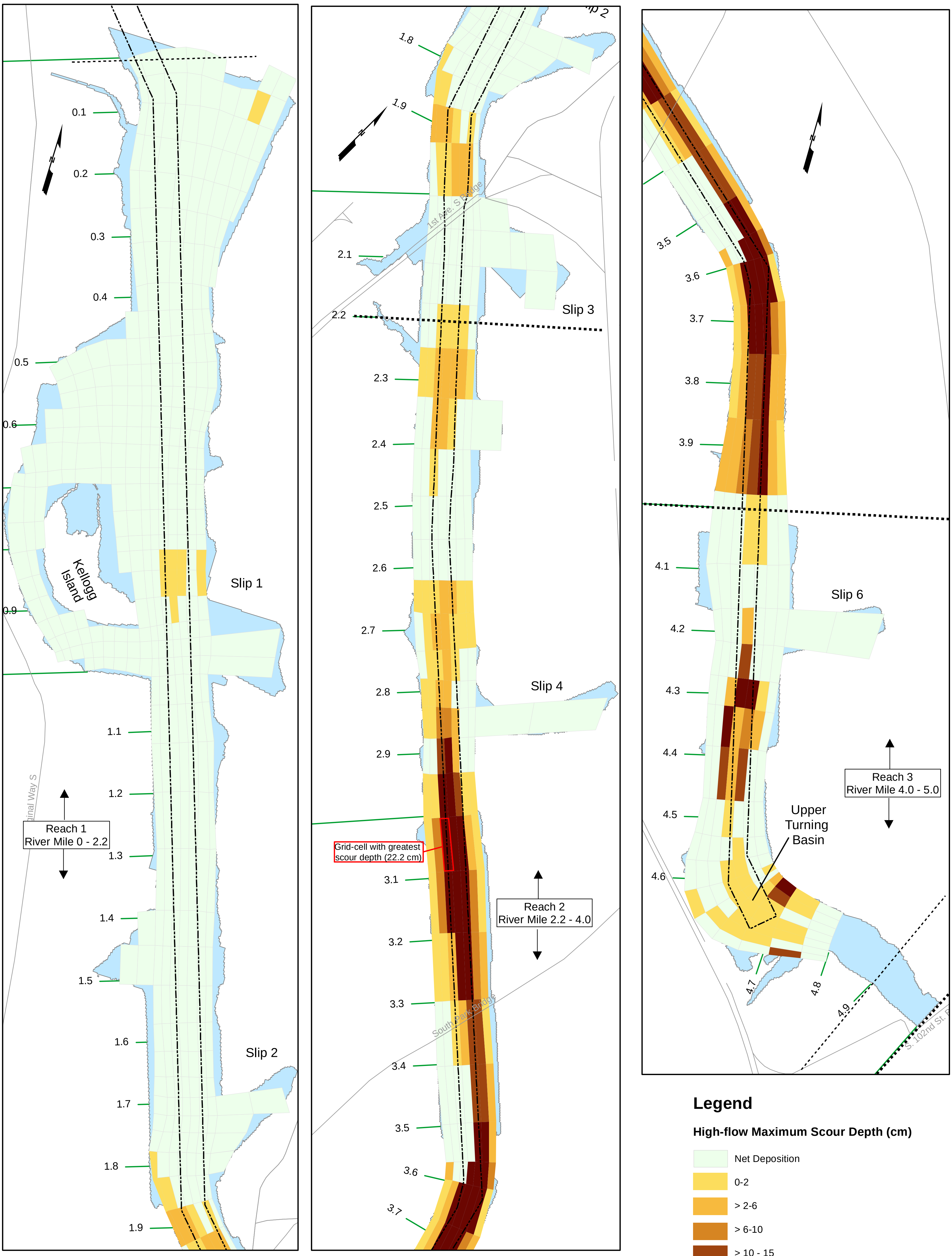


Figure 2-8c LDW Conceptual Site Model for Reach 3





Legend

High-flow Maximum Scour Depth (cm)

🟩	Net Deposition
🟨	0-2
🟧	> 2-6
🟧	> 6-10
🟫	> 10 - 15
🟥	> 15 - 22
🟦	Outside of Model Domain
⋯⋯	Extent of Conceptual Site Model Reach
—	Road
-·-·	Navigation Channel
—	River Mile Marker

Notes:
1. Maximum scour depths from 100-year high-flow event shapefile dated June 2008 (QEA 2008).
2. Maximum scour depth is the depth to which sediment is scoured from the bed any time during a 100-year high-flow event.

Feet
0 200 400 800

L:\Lower Duwamish FS\FS_Final_GISOct2012\FS_GIS_MXDs_Oct12\Section 2\Figure2_9MaxScour.mxd

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Predicted Bed Scour Depth
During 100-Year High-Flow Event

DATE: 10/31/12 | DWRN:MVI/sea | Revision: 0

FIGURE 2-9

Legend

▨ Evidence of Propeller Wash Scour

▨ Overwater Structure

🟦 No 2003 Bathymetric Data Coverage

Mudline Elevation (ft MLLW)

High : 9.5

Low : -53.6

Road

Navigation Channel

River Mile Marker

Notes:
1. Sun-illumination layer generated in ArcGIS 9.2 using October 2003 David Evans and Associates bathymetric survey using the following settings: azimuth 30°, altitude 45°.
2. Overwater structures data created in 2004 by Terralogic GIS, Inc. and Landau Associates, Inc. and modified using 2007 high resolution oblique aerial photography and field investigations.
3. Because the sun-illumination transparency was applied to the mudline elevation, the legend appears darker than the map.

Feet
0 200 400 800

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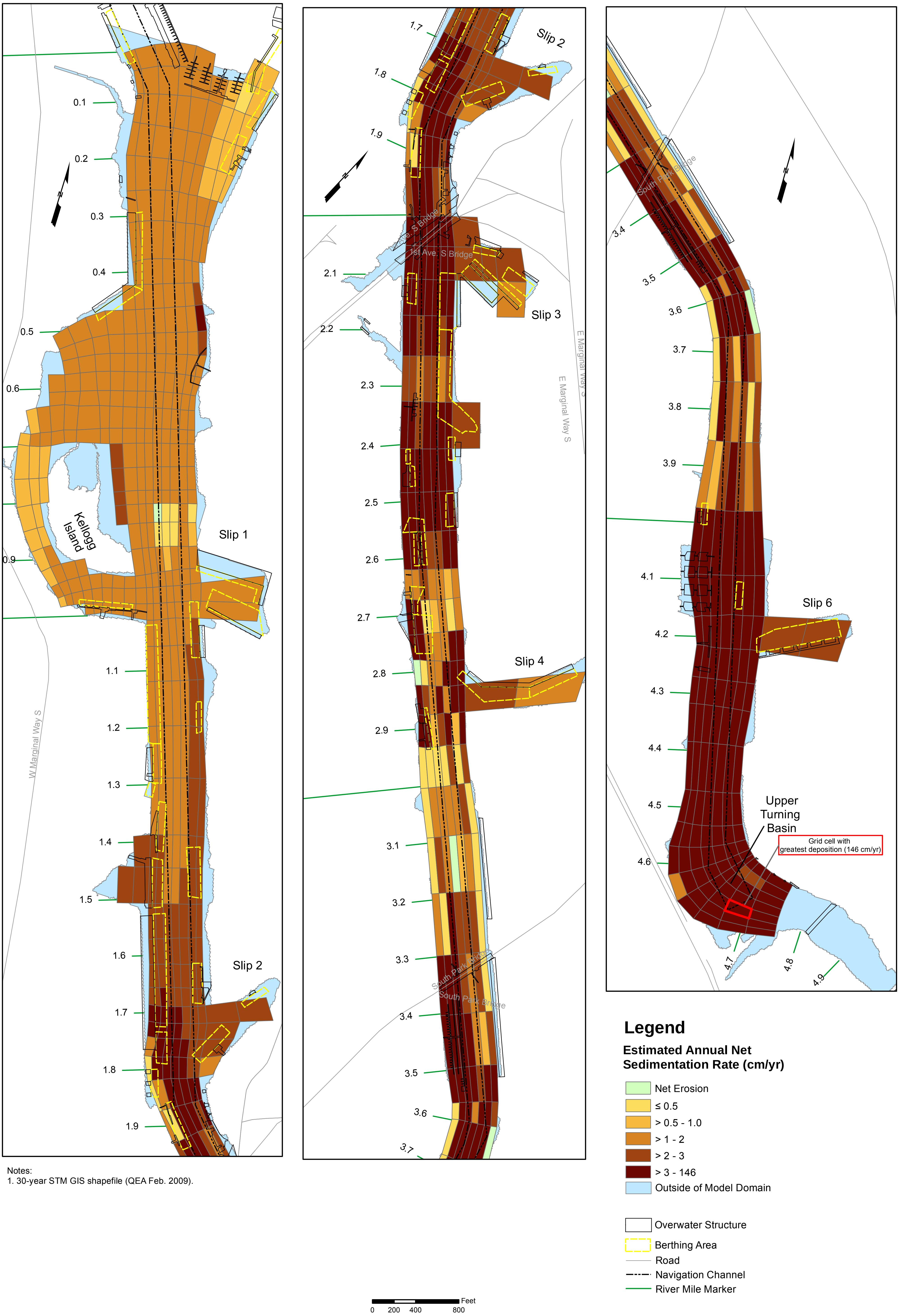
2003 Bathymetry, Overwater Structures, and Areas with Evidence of Propeller Wash Scour

DATE: 10/31/12 | DWRN:MVI/sea | Revision: 1

FIGURE 2-10

L:\Lower Duwamish FS\FS_Final_GISOct2012\FS_GIS_MXDs_Oct12\Section 2\Figure2-10PropScour.mxd



Notes:
1. 30-year STM GIS shapefile (QEA Feb. 2009).

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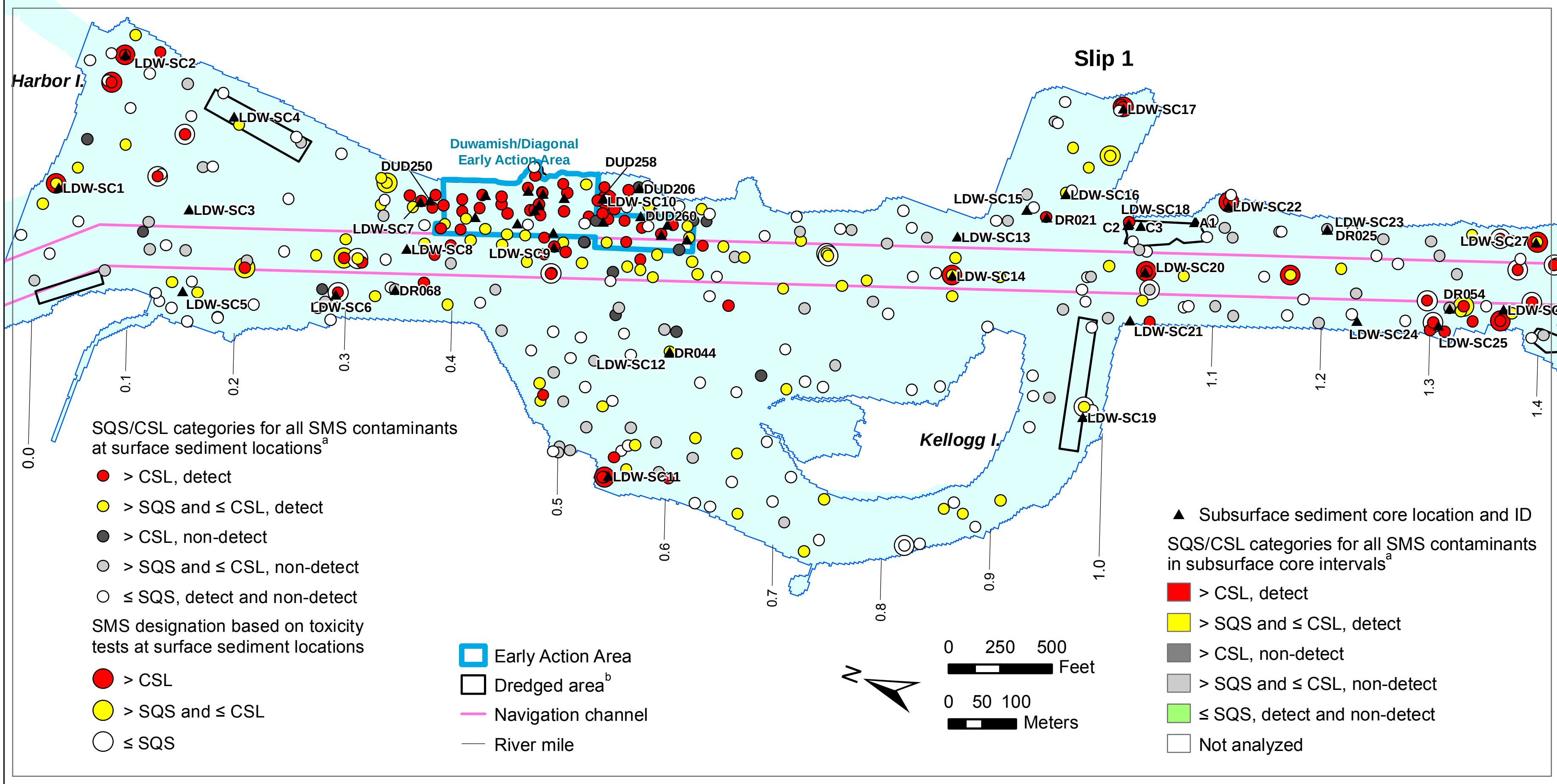
Estimated Annual Net Sedimentation Rates

DATE: 10/31/12 DWRN:MVI/sea Revision: 0

FIGURE 2-11

Subsurface sediment core locations and exceedances of SQS and CSL (chemical criteria and toxicity combined) in surface sediment



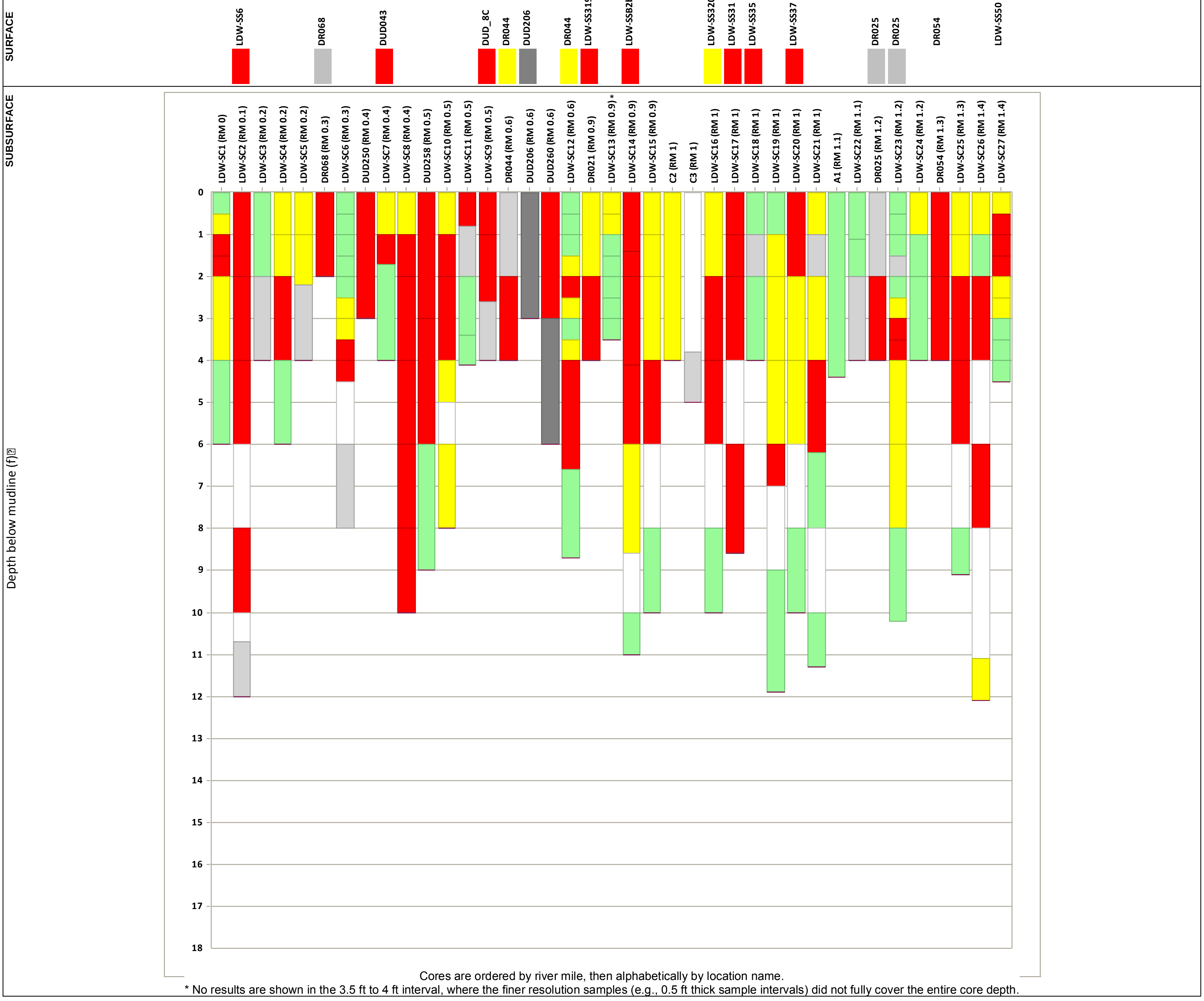
[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Surface sediment data in the Duwamish/Diagonal Early Action Area were collected prior to dredging and capping or thin-layer placement. In other dredged areas, subsurface data were collected prior to dredging.

Note: This map does not include samples in the Duwamish/Diagonal dredged and capped areas.

Exceedances of SQS and CSL in subsurface sediment cores and co-located (within 10 ft) surface sediment samples

Labeled values represent exceedances of SQS and CSL (chemical criteria and toxicity combined) at a surface sediment location within 10 ft of the subsurface sediment core.



Cores are ordered by river mile, then alphabetically by location name.

* No results are shown in the 3.5 ft to 4 ft interval, where the finer resolution samples (e.g., 0.5 ft thick sample intervals) did not fully cover the entire core depth.

Figure 2-12a. Comparisons of Concentrations of all SMS Contaminants to SMS Criteria (SQS or CSL) in Subsurface Sediment Cores, RM 0.0 to RM 1.4

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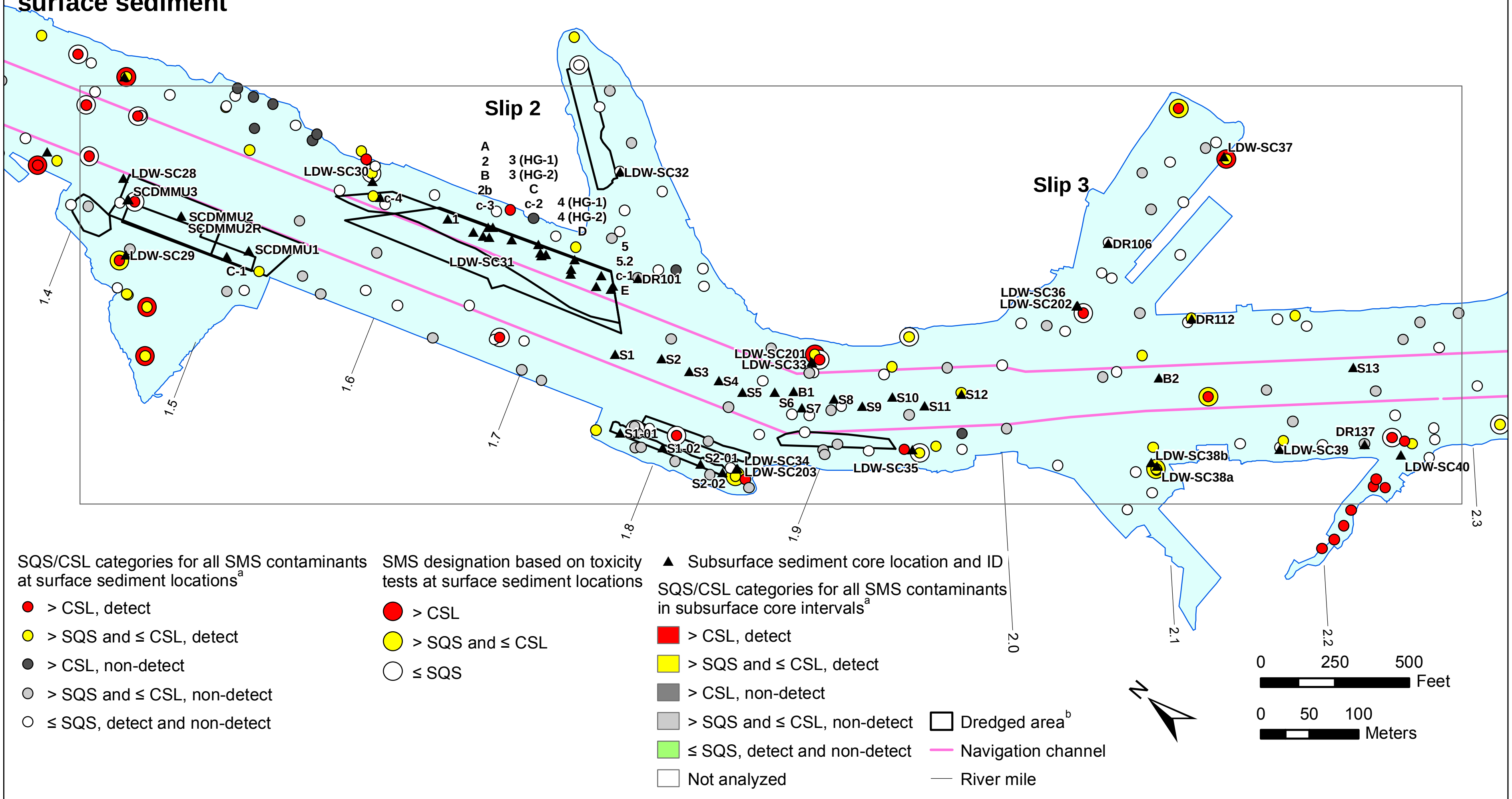
Subsurface sediment core locations and exceedances of SQS and CSL (chemical criteria and toxicity combined) in surface sediment

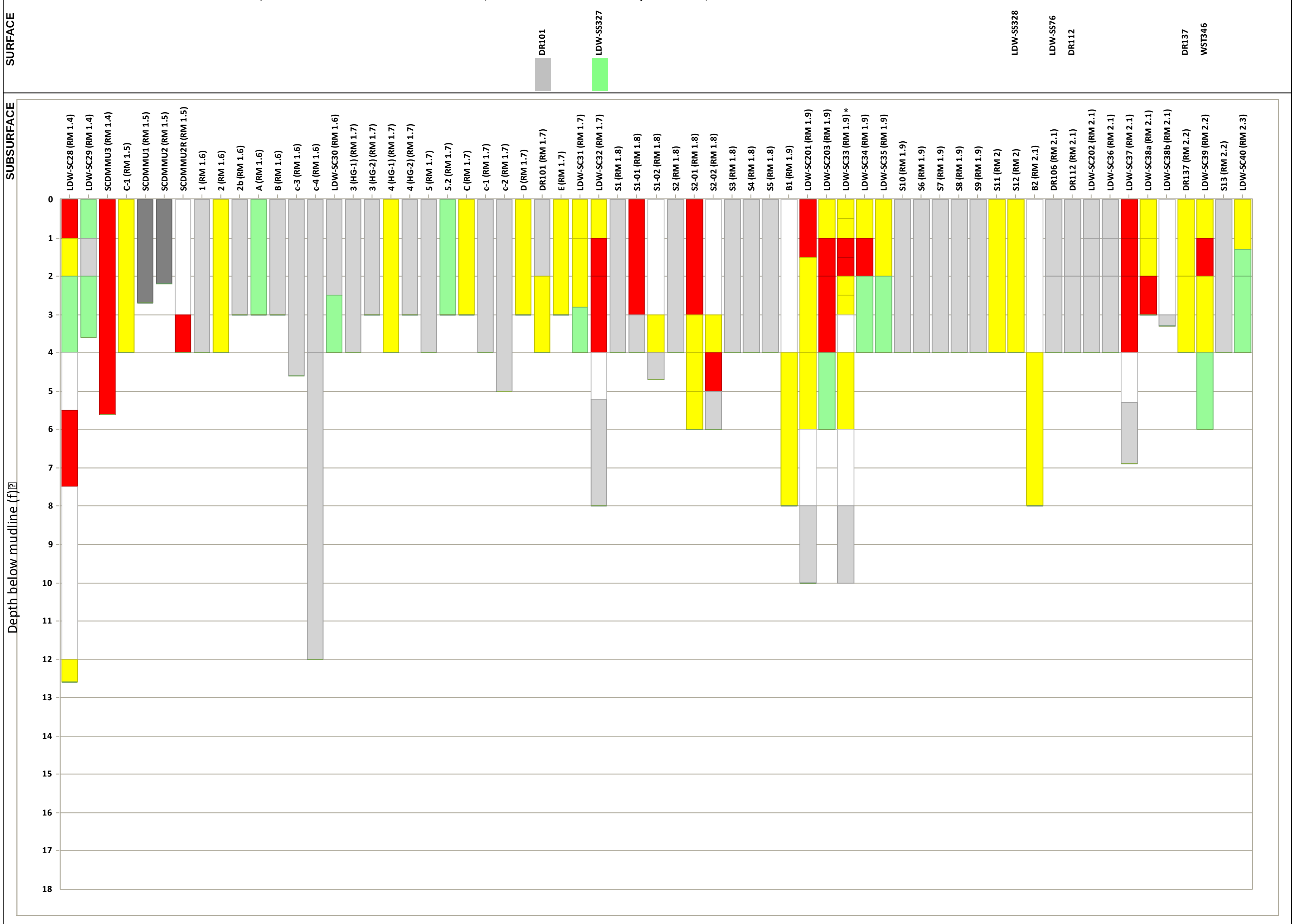


[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Subsurface sediment data in dredged areas were collected prior to dredging.

Exceedances of SQS and CSL in subsurface sediment cores and co-located (within 10 ft) surface sediment samples

Labeled values represent exceedances of SQS and CSL (chemical criteria and toxicity combined) at a surface sediment location within 10 ft of the subsurface sediment core.



Cores are ordered by river mile, then alphabetically by location name.

* No results are shown in the 3 ft to 4 ft interval, where the finer resolution samples (e.g., 0.5 ft thick sample intervals) did not fully cover the entire core depth.

Figure 2-12b. Comparisons of Concentrations of all SMS Contaminants to SMS Criteria (SQS or CSL) in Subsurface Sediment Cores, RM 1.4 to RM 2.3

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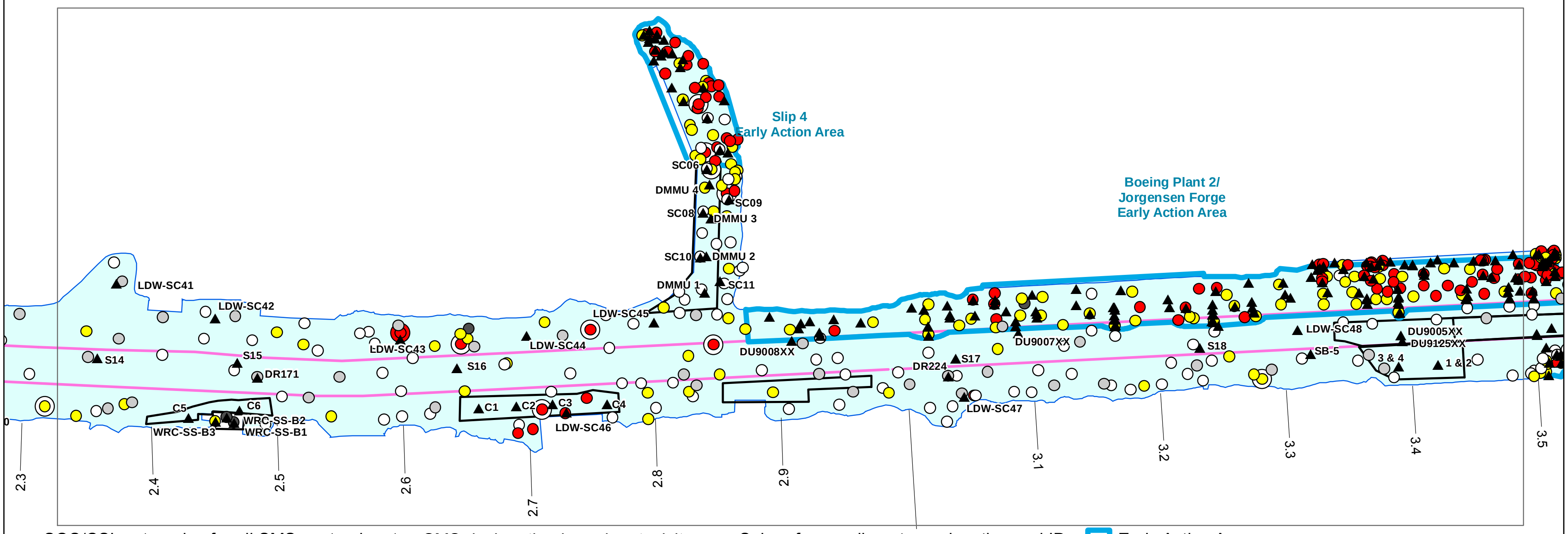
Subsurface sediment core locations and exceedances of SQS and CSL (chemical criteria and toxicity combined) in surface sediment



SQS/CSL categories for all SMS contaminants at surface sediment locations[a]

- ● > CSL, detect
- ● > SQS and ≤ CSL, detect
- ● > CSL, non-detect
- ● > SQS and ≤ CSL, non-detect
- ○ ≤ SQS, detect and non-detect

SMS designation based on toxicity tests at surface sediment locations

- ● > CSL
- ● > SQS and ≤ CSL
- ○ ≤ SQS

▲ Subsurface sediment core location and ID

SQS/CSL categories for all SMS contaminants in subsurface core intervals[a]

- 🟥 > CSL, detect
- 🟨 > SQS and ≤ CSL, detect
- ■ > CSL, non-detect
- ■ > SQS and ≤ CSL, non-detect
- 🟩 ≤ SQS, detect and non-detect
- ☐ Not analyzed

- ☐ Early Action Area
- ☐ Dredged area[b]
- Navigation channel
- River mile

N

0 250 500 Feet

0 50 100 Meters

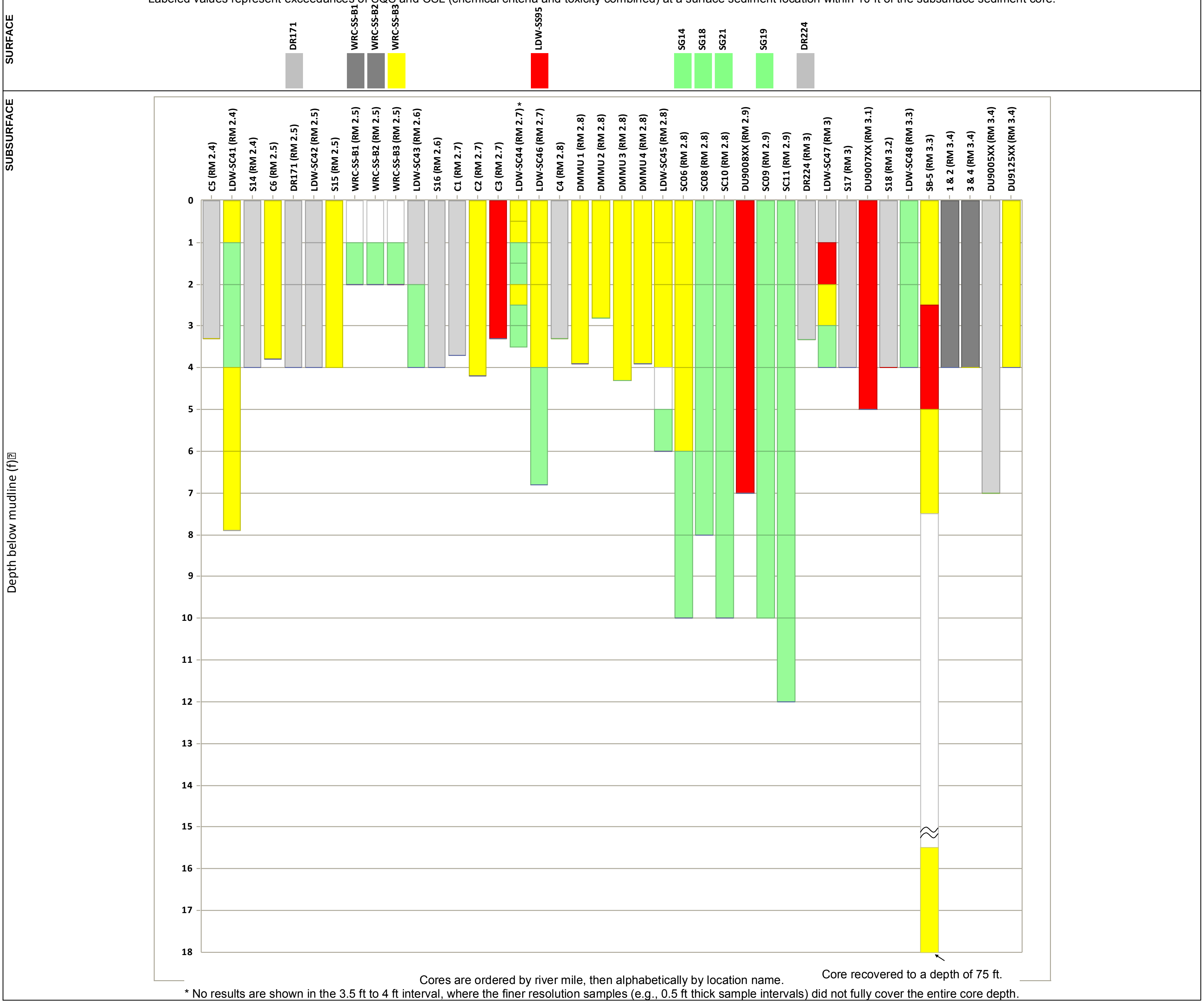
[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Subsurface sediment data in dredged areas were collected prior to dredging.

Note: This map does not include samples in the Slip 4 or Boeing Plant 2/Jorgensen Forge Early Action Areas.

Exceedances of SQS and CSL in subsurface sediment cores and co-located (within 10 ft) surface sediment samples

Labeled values represent exceedances of SQS and CSL (chemical criteria and toxicity combined) at a surface sediment location within 10 ft of the subsurface sediment core.



Core recovered to a depth of 75 ft.

Cores are ordered by river mile, then alphabetically by location name.

* No results are shown in the 3.5 ft to 4 ft interval, where the finer resolution samples (e.g., 0.5 ft thick sample intervals) did not fully cover the entire core depth.

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Figure 2-12c. Comparisons of Concentrations of all SMS Contaminants to SMS Criteria (SQS or CSL) in Subsurface Sediment Cores, RM 2.3 to RM 3.5

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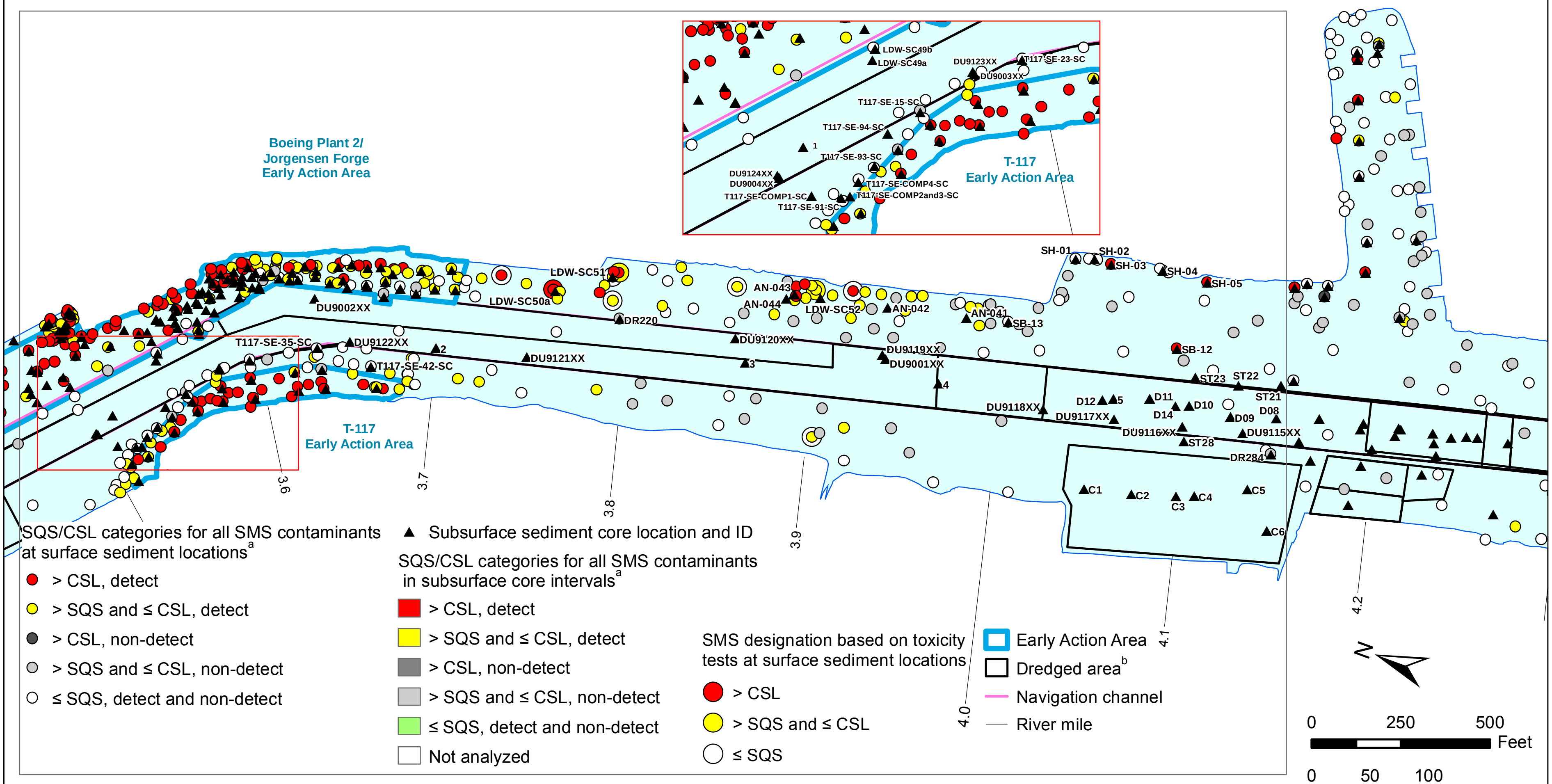
Subsurface sediment core locations and exceedances of SQS and CSL (chemical criteria and toxicity combined) in surface sediment

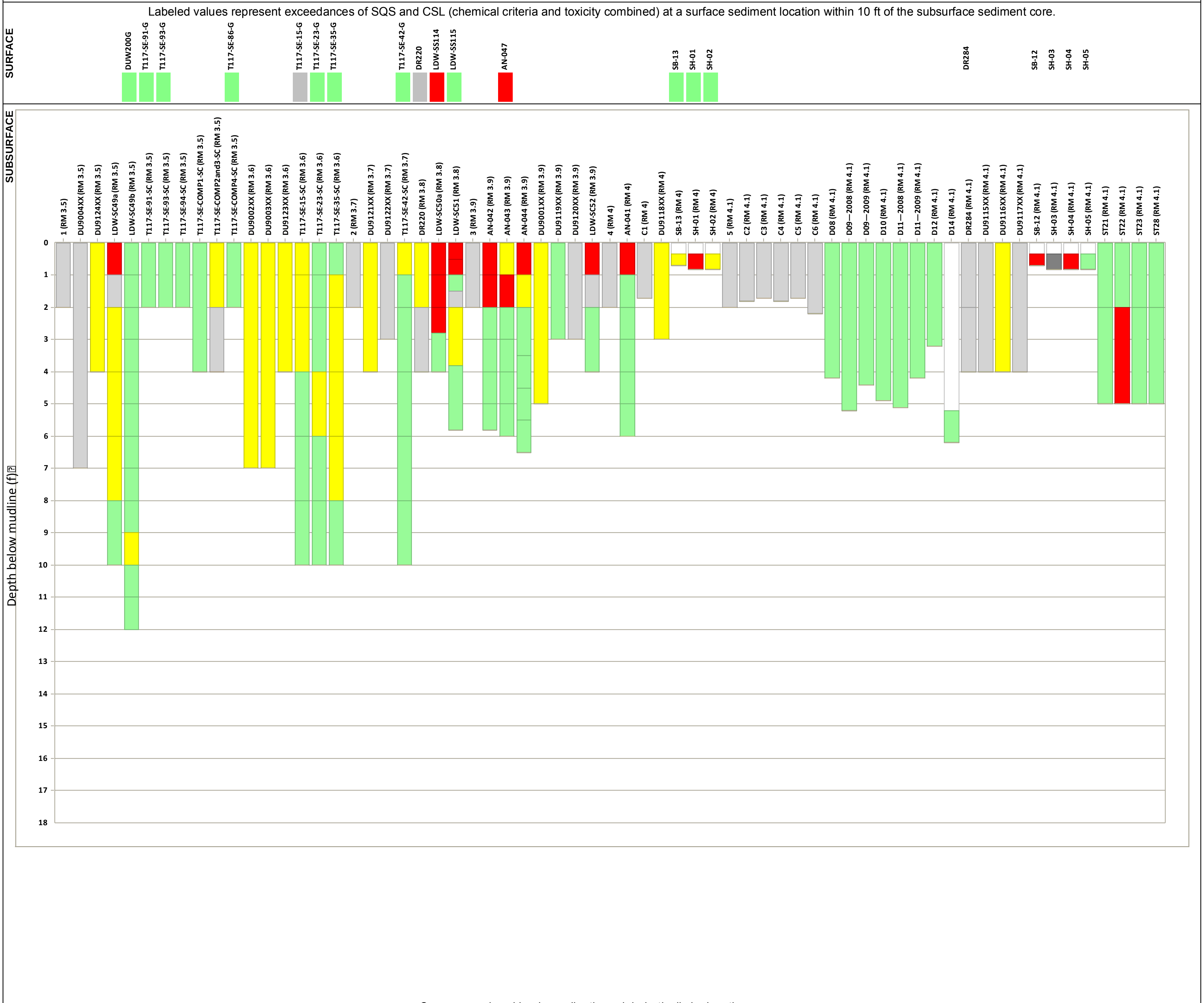


[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Subsurface sediment data in dredged areas were collected prior to dredging.

Note: This map does not include samples in the Boeing Plant 2/Jorgensen Forge or T-117 Early Action Areas.

Exceedances of SQS and CSL in subsurface sediment cores and co-located (within 10 ft) surface sediment samples



Cores are ordered by river mile, then alphabetically by location name.

Figure 2-12d. Comparisons of Concentrations of all SMS Contaminants to SMS Criteria (SQS or CSL) in Subsurface Sediment Cores, RM 3.5 to RM 4.3

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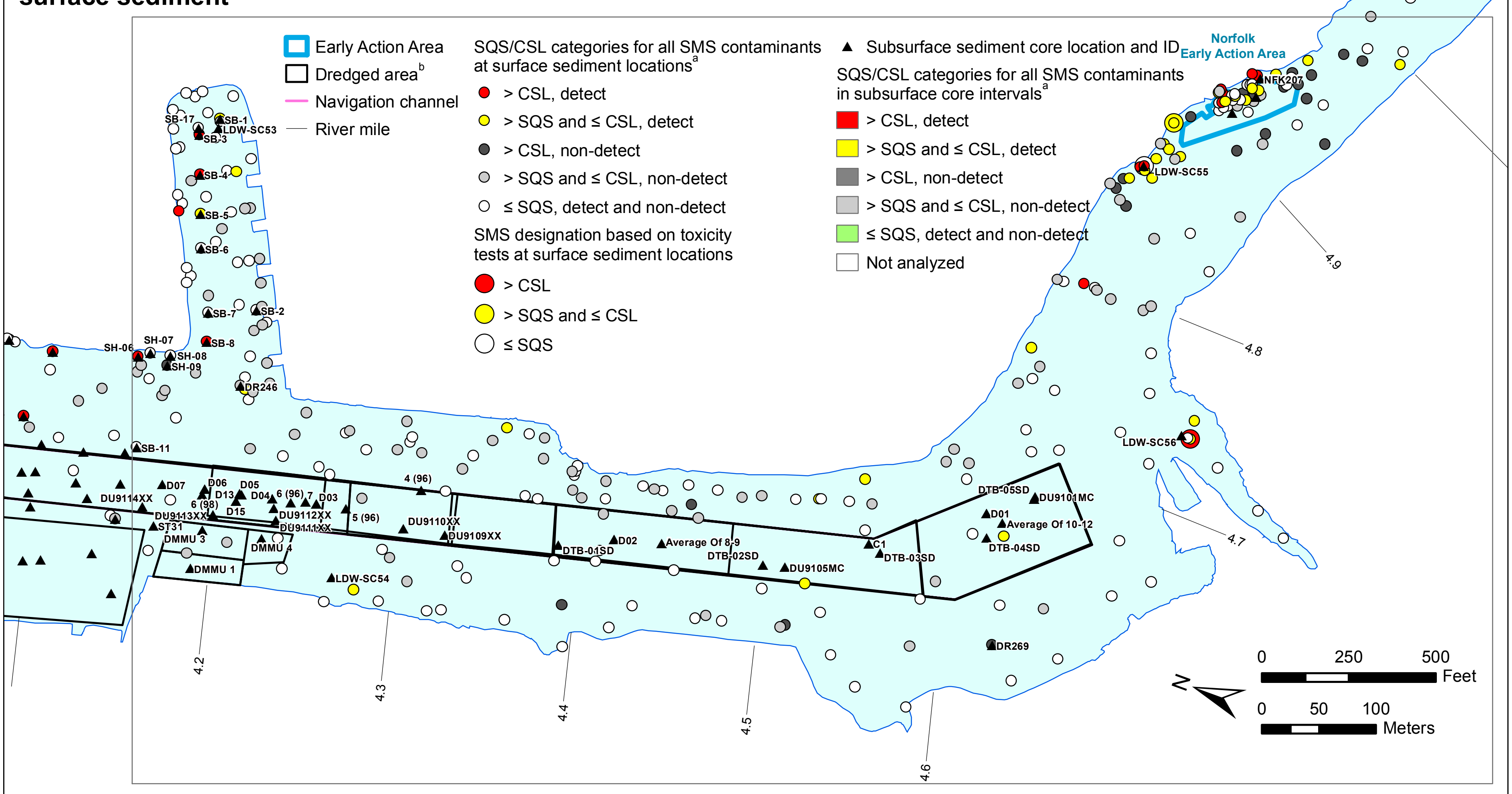
Subsurface sediment core locations and exceedances of SQS and CSL (chemical criteria and toxicity combined) in surface sediment

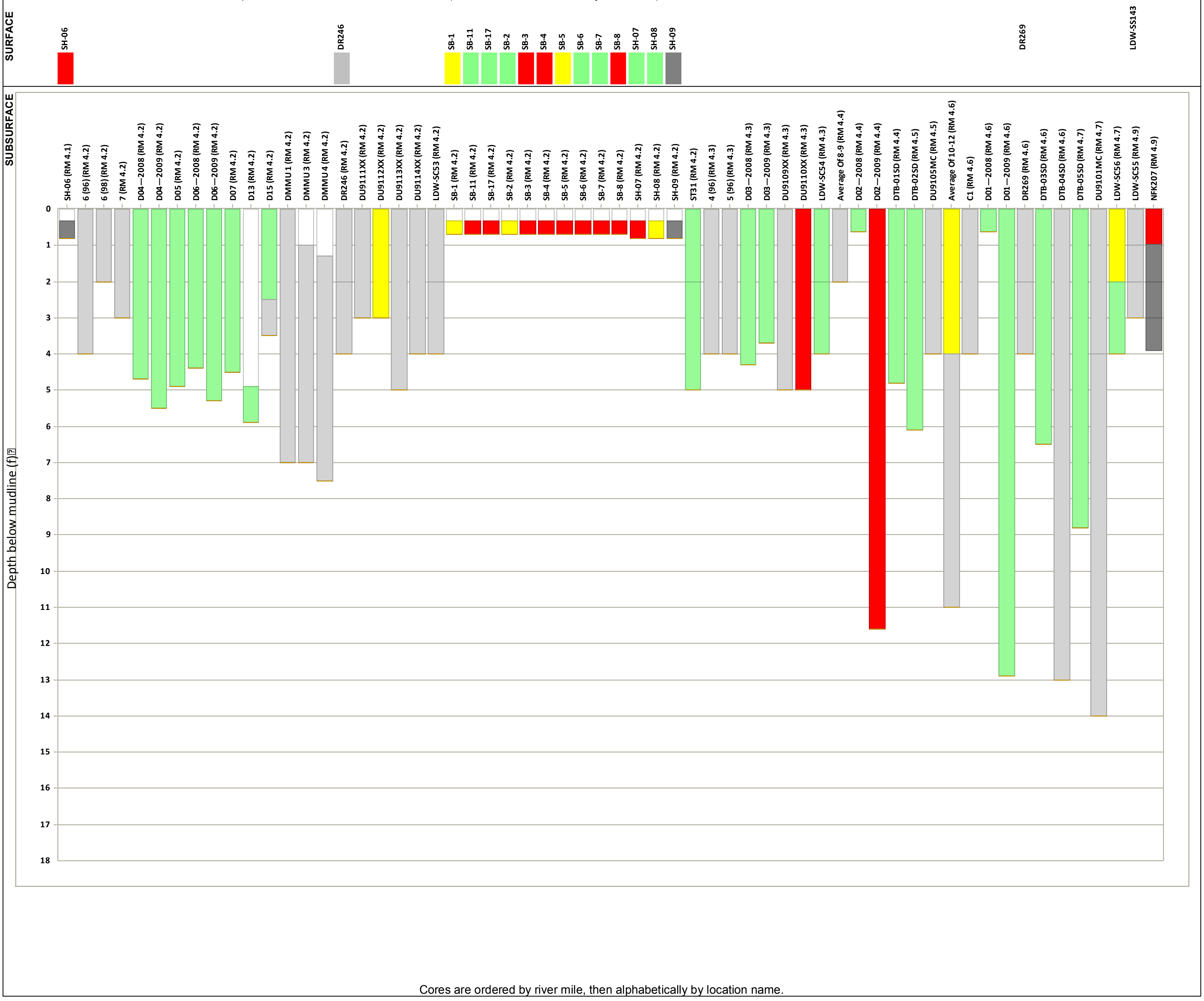


[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Subsurface data in the Norfolk Early Action Area were collected prior to dredging and capping. In other dredged areas, subsurface data were collected prior to dredging.

Exceedances of SQS and CSL in subsurface sediment cores and co-located (within 10 ft) surface sediment samples

Labeled values represent exceedances of SQS and CSL (chemical criteria and toxicity combined) at a surface sediment location within 10 ft of the subsurface sediment core.



Cores are ordered by river mile, then alphabetically by location name.

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Figure 2-12e. Comparisons of Concentrations of all SMS Contaminants to SMS Criteria (SQS or CSL) in Subsurface Sediment Cores, RM 4.3 to RM 5.0

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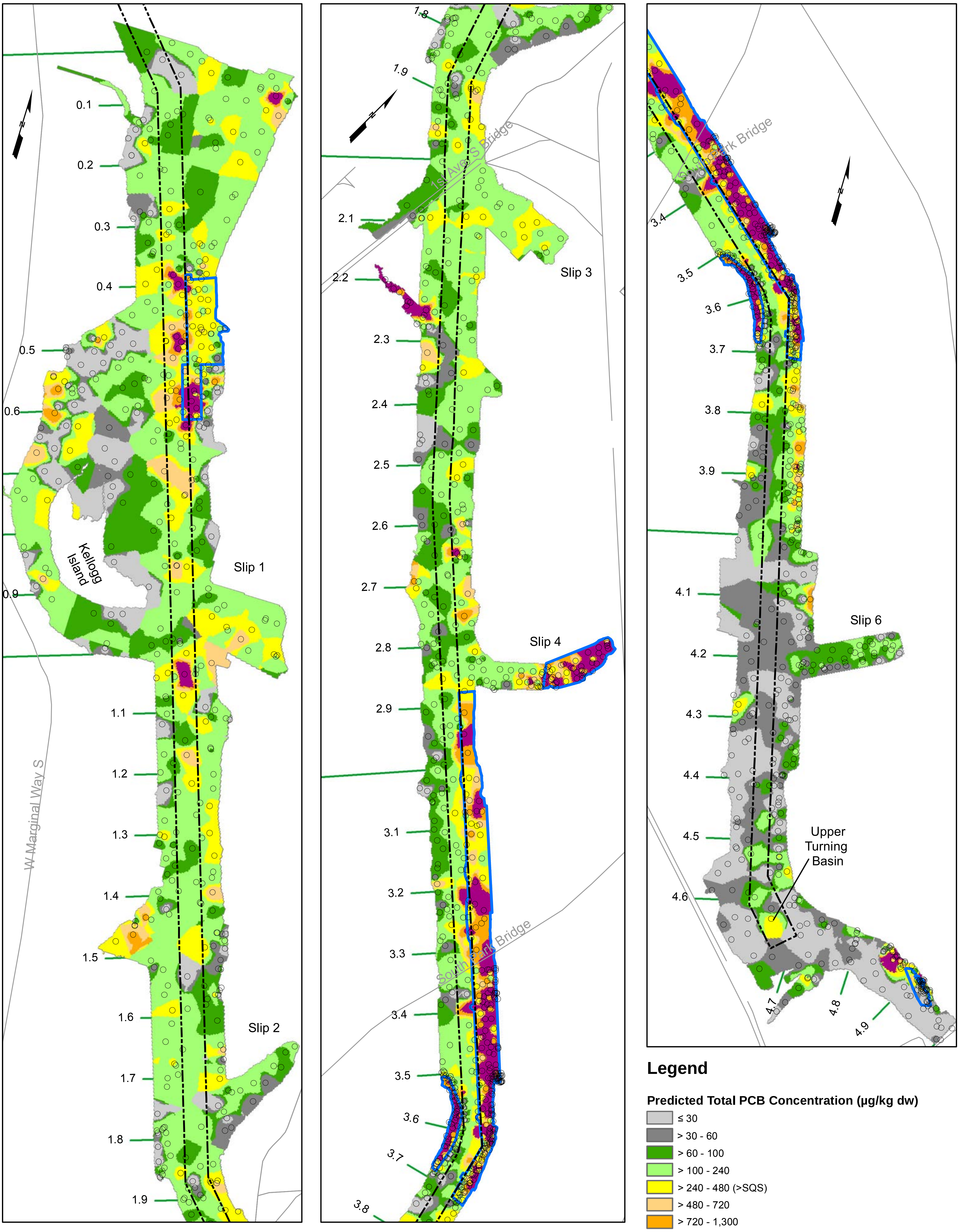

Legend

Predicted Total PCB Concentration (µg/kg dw)

- ≤ 30
- > 30 - 60
- > 60 - 100
- > 100 - 240
- > 240 - 480 (>SQS)
- > 480 - 720
- > 720 - 1,300
- > 1,300 (>CSL)

○ PCB Sample Location

Road

Navigation Channel

River Mile Marker

Early Action Area

Notes:
1. Grid interpolated using the following parameters: Power 5, nearest neighbors 10/1, search radius 150x150 ft.
2. Sampling dates of the data range from 1991 to 2010.
3. PCB data from FS baseline dataset dated April 28, 2010.
4. SQS value of 240 µg/kg dw based on conversion of 12 mg/kg oc to a dry weight value using 2% TOC.
5. Two outliers (2,900,000 and 230,000 µg/kg dw) at the head of the Trotsky inlet (RM 2.2) were excluded from use in the interpolation.

Feet
0 200 400 800

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Interpolated Total PCB Distribution in Surface Sediment

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FIGURE 2-13

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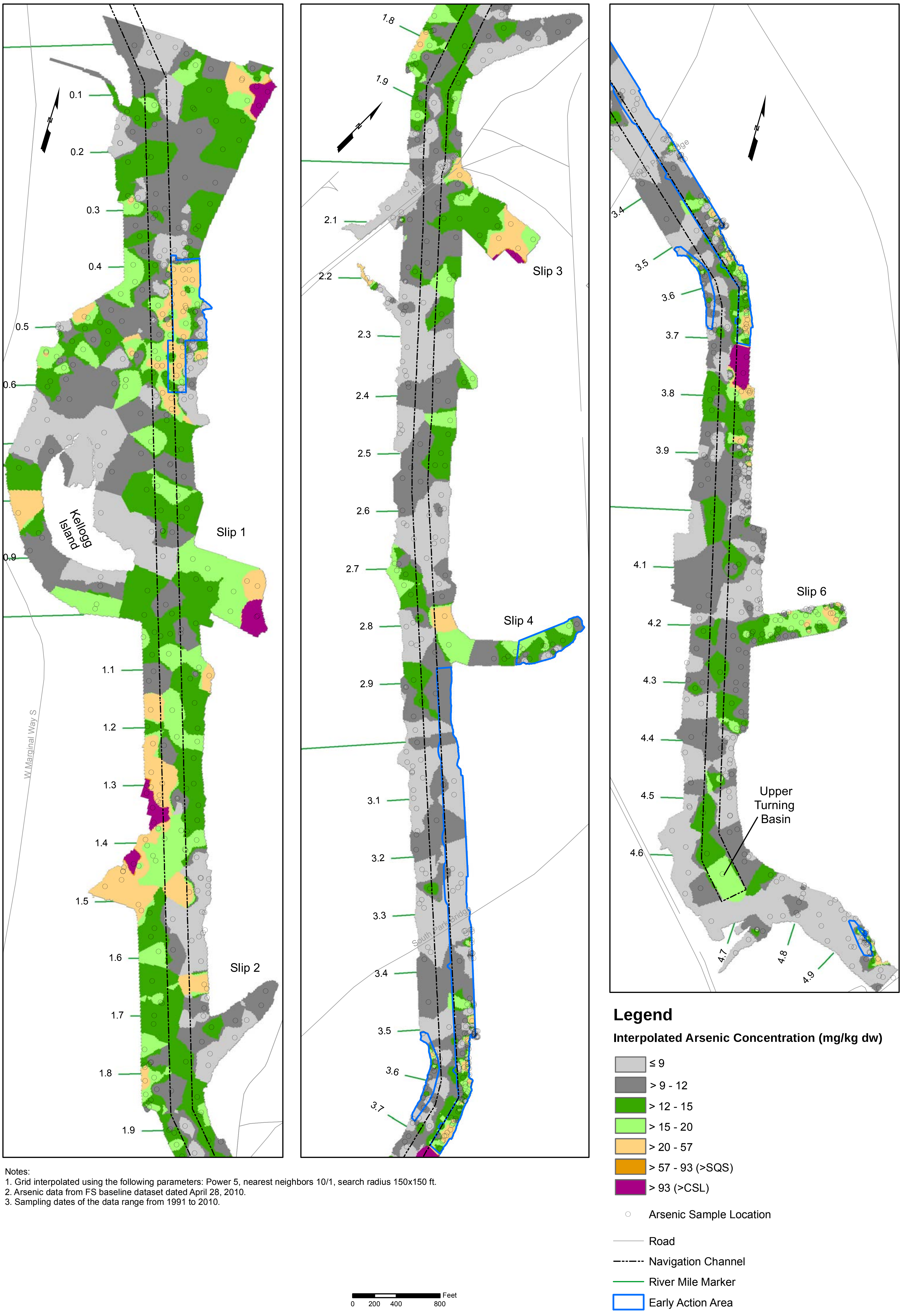

Notes:
1. Grid interpolated using the following parameters: Power 5, nearest neighbors 10/1, search radius 150x150 ft.
2. Arsenic data from FS baseline dataset dated April 28, 2010.
3. Sampling dates of the data range from 1991 to 2010.

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Interpolated Arsenic Distribution in Surface Sediment

DATE: 10/31/12 | DWRN: MVI/sea | Revision: 0

FIGURE 2-14

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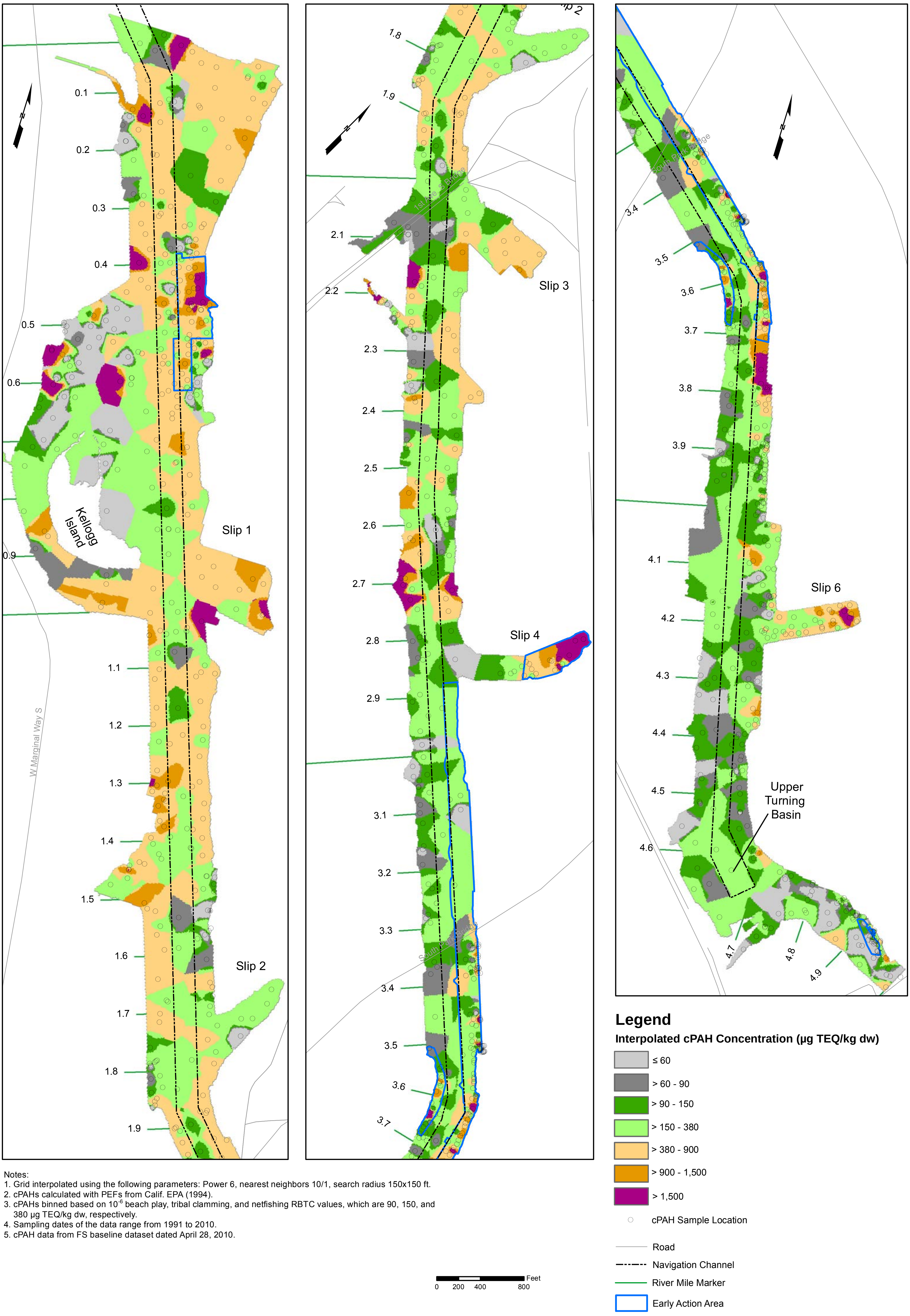

Notes:
1. Grid interpolated using the following parameters: Power 6, nearest neighbors 10/1, search radius 150x150 ft.
2. cPAHs calculated with PEFs from Calif. EPA (1994).
3. cPAHs binned based on 10^{-6} beach play, tribal clamming, and netfishing RBTC values, which are 90, 150, and 380 µg TEQ/kg dw, respectively.
4. Sampling dates of the data range from 1991 to 2010.
5. cPAH data from FS baseline dataset dated April 28, 2010.

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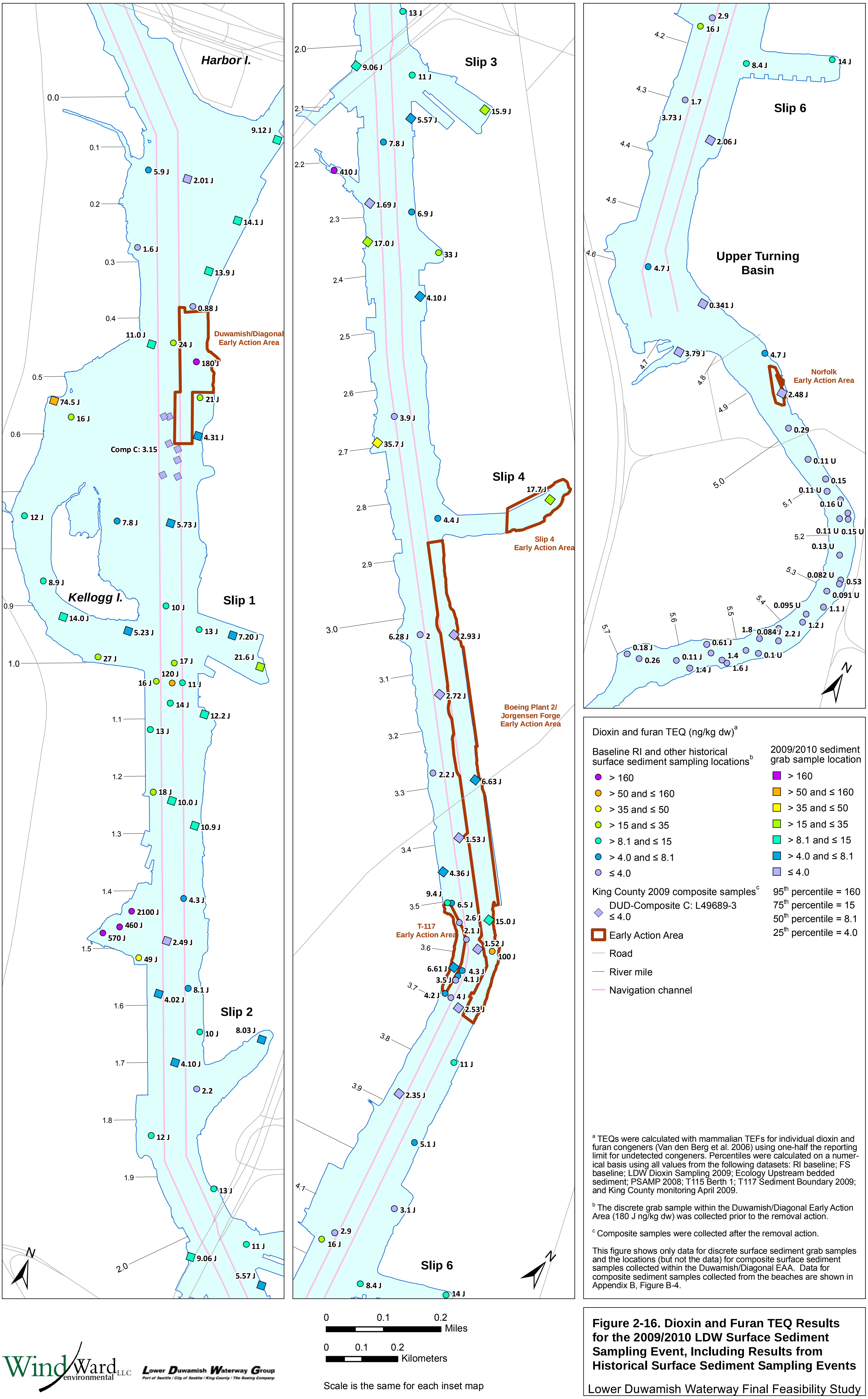
Interpolated cPAH Distribution in Surface Sediment

FIGURE 2-15



[a] TEQs were calculated with mammalian TEFs for individual dioxin and furan congeners (Van den Berg et al. 2006) using one-half the reporting limit for undetected congeners. Percentiles were calculated on a numerical basis using all values from the following datasets: RI baseline; FS baseline; LDW Dioxin Sampling 2009; Ecology Upstream bedded sediment; PSAMP 2008; T115 Berth 1; T117 Sediment Boundary 2009; and King County monitoring April 2009.

[b] The discrete grab sample within the Duwamish/Diagonal Early Action Area (180 J ng/kg dw) was collected prior to the removal action.

[c] Composite samples were collected after the removal action.

This figure shows only data for discrete surface sediment grab samples and the locations (but not the data) for composite surface sediment samples collected within the Duwamish/Diagonal EAA. Data for composite sediment samples collected from the beaches are shown in Appendix B, Figure B-4.

Figure 2-16. Dioxin and Furan TEQ Results for the 2009/2010 LDW Surface Sediment Sampling Event, Including Results from Historical Surface Sediment Sampling Events

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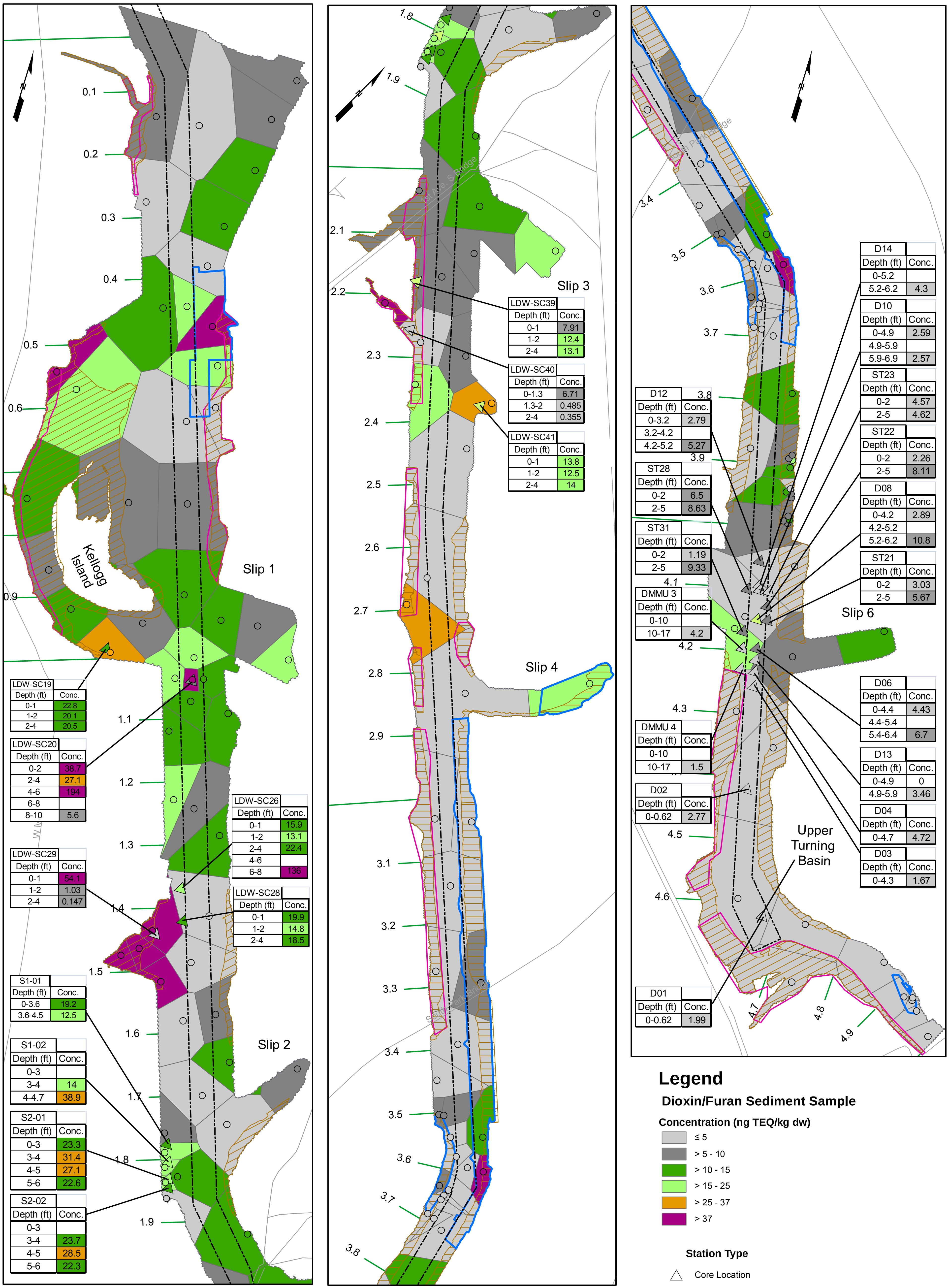

LDW-SC19	
Depth (ft)	Conc.
0-1	22.8
1-2	20.1
2-4	20.5

LDW-SC20	
Depth (ft)	Conc.
0-2	38.7
2-4	27.1
4-6	194
6-8	
8-10	5.6

LDW-SC29	
Depth (ft)	Conc.
0-1	54.1
1-2	1.03
2-4	0.147

LDW-SC26	
Depth (ft)	Conc.
0-1	15.9
1-2	13.1
2-4	22.4
4-6	
6-8	136

LDW-SC28	
Depth (ft)	Conc.
0-1	19.9
1-2	14.8
2-4	18.5

S1-01	
Depth (ft)	Conc.
0-3.6	19.2
3.6-4.5	12.5

S1-02	
Depth (ft)	Conc.
0-3	
3-4	14
4-4.7	38.9

S2-01	
Depth (ft)	Conc.
0-3	23.3
3-4	31.4
4-5	27.1
5-6	22.6

S2-02	
Depth (ft)	Conc.
0-3	
3-4	23.7
4-5	28.5
5-6	22.3

LDW-SC39	
Depth (ft)	Conc.
0-1	7.91
1-2	12.4
2-4	13.1

LDW-SC40	
Depth (ft)	Conc.
0-1.3	6.71
1.3-2	0.485
2-4	0.355

LDW-SC41	
Depth (ft)	Conc.
0-1	13.8
1-2	12.5
2-4	14

D12	
Depth (ft)	Conc.
0-3.2	2.79
3.2-4.2	
4.2-5.2	5.27

ST28	
Depth (ft)	Conc.
0-2	6.5
2-5	8.63

ST31	
Depth (ft)	Conc.
0-2	1.19
2-5	9.33

DMMU 3	
Depth (ft)	Conc.
0-10	
10-17	4.2

DMMU 4	
Depth (ft)	Conc.
0-10	
10-17	1.5

D02	
Depth (ft)	Conc.
0-0.62	2.77

D01	
Depth (ft)	Conc.
0-0.62	1.99

D14	
Depth (ft)	Conc.
0-5.2	
5.2-6.2	4.3

D10	
Depth (ft)	Conc.
0-4.9	2.59
4.9-5.9	
5.9-6.9	2.57

ST23	
Depth (ft)	Conc.
0-2	4.57
2-5	4.62

ST22	
Depth (ft)	Conc.
0-2	2.26
2-5	8.11

D08	
Depth (ft)	Conc.
0-4.2	2.89
4.2-5.2	
5.2-6.2	10.8

ST21	
Depth (ft)	Conc.
0-2	3.03
2-5	5.67

D06	
Depth (ft)	Conc.
0-4.4	4.43
4.4-5.4	
5.4-6.4	6.7

D13	
Depth (ft)	Conc.
0-4.9	0
4.9-5.9	3.46

D04	
Depth (ft)	Conc.
0-4.7	4.72

D03	
Depth (ft)	Conc.
0-4.3	1.67

Legend

Dioxin/Furan Sediment Sample

Concentration (ng TEQ/kg dw)

■	≤ 5
■	> 5 - 10
🟩	> 10 - 15
🟩	> 15 - 25
🟧	> 25 - 37
🟪	> 37

Station Type

△	Core Location
○	Surface Sediment Sample

▨	Potential Clamming Area
☐	Beach Play Area
☐	Early Action Area
—	Road
-·-	Navigation Channel
—	River Mile Marker

Notes:
1. Thiessen polygons derived from 123 surface sediment locations; dataset includes the following surface sediment data: 25 RI samples, 41 2009/2010 LDWG samples, 26 EPA Site Investigation samples, 8 T117 perimeter samples, 5 T115 intertidal samples, 5 Ecology bedded sediment samples, 12 Kenworth PACCAR samples, and 1 location from Duwamish/Diagonal 2009 composite C.
2. Sampling dates range from 1998 to 2010.
3. Core locations symbolized by concentration in shallowest interval analyzed. The cores were not used to draw the Thiessen polygons.
4. The Thiessen polygons shown in this figure are based only on data for discrete surface sediment grab samples. Data for composite sediment samples collected from the beaches are shown in Appendix B, Figure B-4.

Core ID

DMMU 3	
Depth (ft)	Conc.
0-10	
10-17	4.2

Skipped Interval
Sample Interval
No Data
Concentration (ng TEQ/kg dw)

0 200 400 800 Feet

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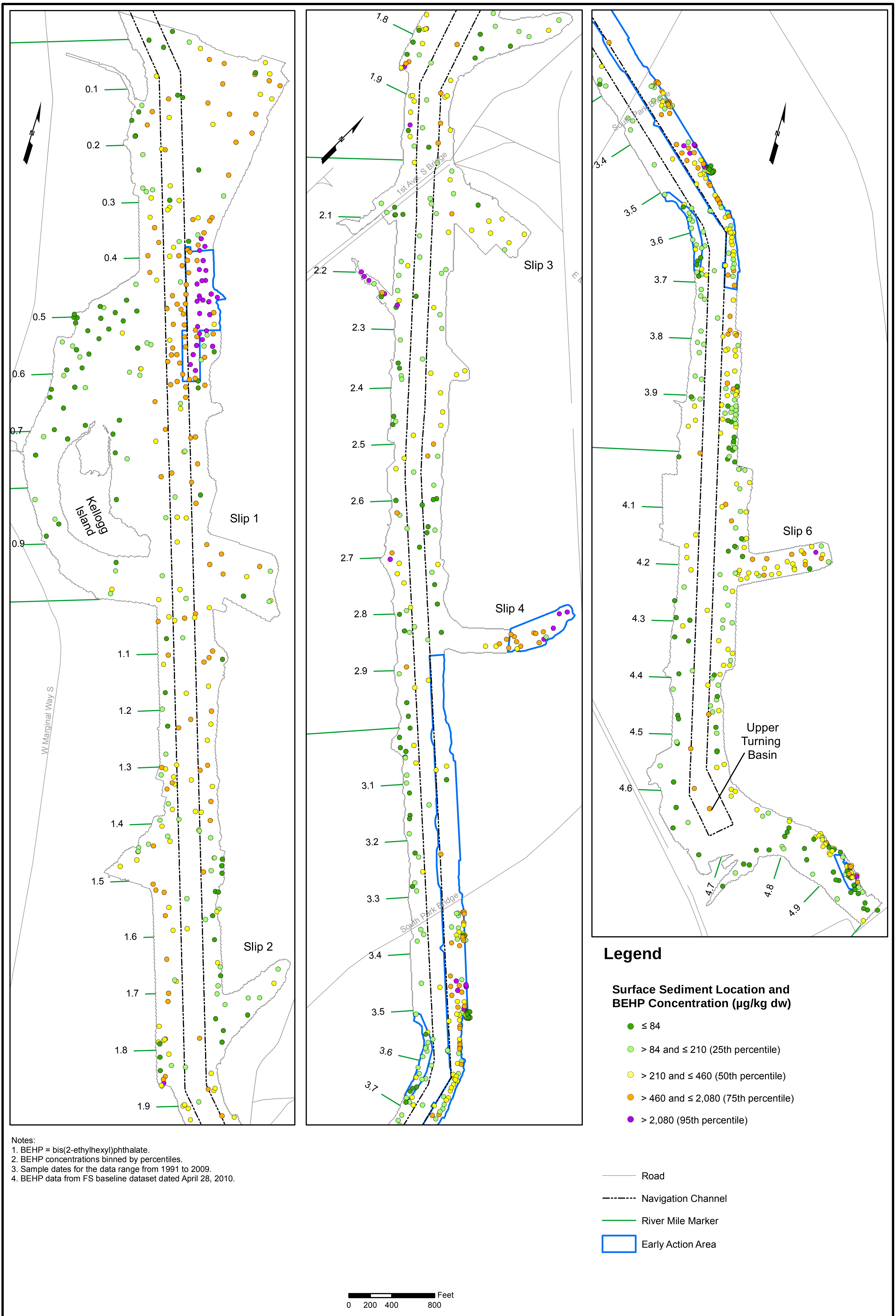
Distribution of Dioxins/Furans in Surface and Subsurface Sediment

FIGURE 2-17



Notes:
1. BEHP = bis(2-ethylhexyl)phthalate.
2. BEHP concentrations binned by percentiles.
3. Sample dates for the data range from 1991 to 2009.
4. BEHP data from FS baseline dataset dated April 28, 2010.

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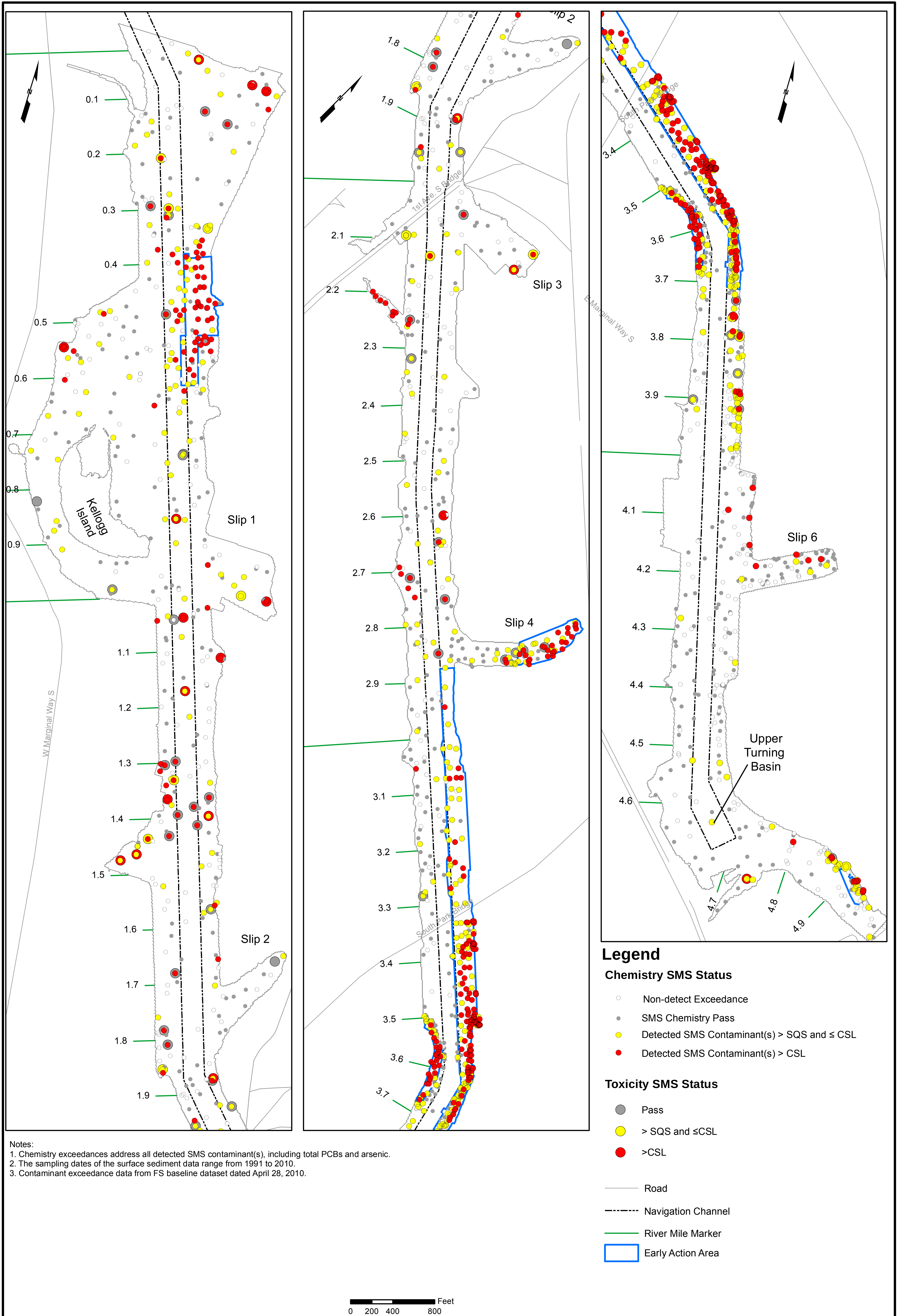
Distribution of BEHP in Surface Sediment

FIGURE 2-18



Notes:
1. Chemistry exceedances address all detected SMS contaminant(s), including total PCBs and arsenic.
2. The sampling dates of the surface sediment data range from 1991 to 2010.
3. Contaminant exceedance data from FS baseline dataset dated April 28, 2010.

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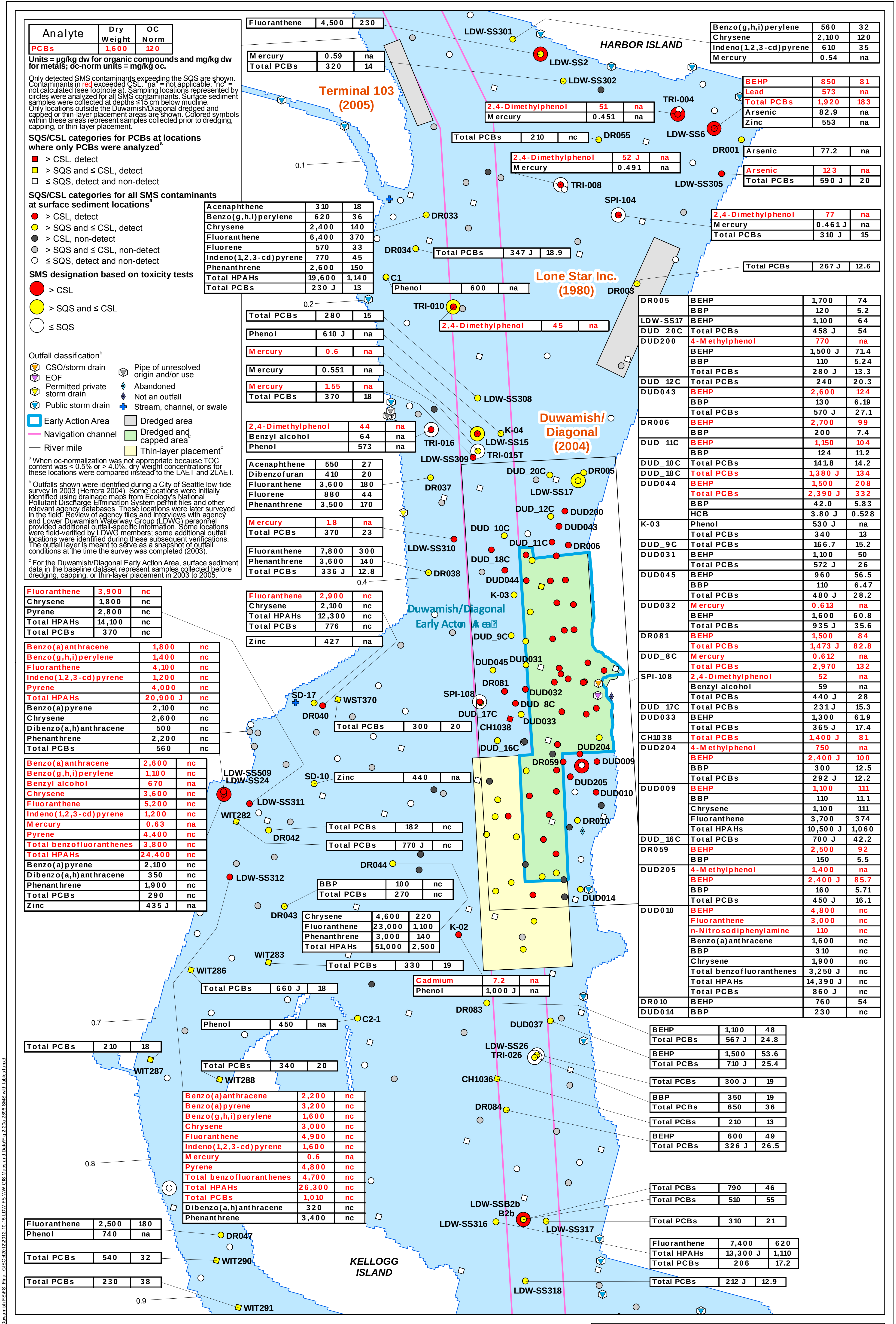
Distribution of SMS Toxicity and Chemistry Status in Surface Sediment

FIGURE 2-19



Analyte	Dry Weight	OC Norm
PCBs	1,600	120

Units = µg/kg dw for organic compounds and mg/kg dw for metals; oc-norm units = mg/kg oc.

Only detected SMS contaminants exceeding the SQS are shown. Contaminants in red exceeded CSL. "na" = not applicable; "nc" = not calculated (see footnote a). Sampling locations represented by circles were analyzed for all SMS contaminants. Surface sediment samples were collected at depths ≤15 cm below mudline. Only locations outside the Duwamish/Diagonal dredged and capped or thin-layer placement areas are shown. Colored symbols within these areas represent samples collected prior to dredging, capping, or thin-layer placement.

SQS/CSL categories for PCBs at locations where only PCBs were analyzed[a]

- 🟥 > CSL, detect
- 🟨 > SQS and ≤ CSL, detect
- ☐ ≤ SQS, detect and non-detect

SQS/CSL categories for all SMS contaminants at surface sediment locations[a]

- 🔴 > CSL, detect
- 🟡 > SQS and ≤ CSL, detect
- ● > CSL, non-detect
- ◐ > SQS and ≤ CSL, non-detect
- ○ ≤ SQS, detect and non-detect

SMS designation based on toxicity tests

- 🔴 > CSL
- 🟡 > SQS and ≤ CSL
- ○ ≤ SQS

Outfall classification[b]

- ⬡ CSO/storm drain
- ⬡ EOF
- ⬡ Permitted private storm drain
- ⬡ Public storm drain
- ⬡ Pipe of unresolved origin and/or use
- ◆ Abandoned
- ◆ Not an outfall
- ✚ Stream, channel, or swale
- ☐ Early Action Area
- — Navigation channel
- — River mile
- ▨ Dredged area
- 🟩 Dredged and capped area[c]
- 🟨 Thin-layer placement[c]

[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and Lower Duwamish Waterway Group (LDWG) personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications. The outfall layer is meant to serve as a snapshot of outfall conditions at the time the survey was completed (2003).

[c] For the Duwamish/Diagonal Early Action Area, surface sediment data in the baseline dataset represent samples collected before dredging, capping, or thin-layer placement in 2003 to 2005.

Fluoranthene	3,900	nc
Chrysene	1,800	nc
Pyrene	2,800	nc
Total HPAHs	14,100	nc
Total PCBs	370	nc

Benzo(a)anthracene	1,800	nc
Benzo(g,h,i)perylene	1,400	nc
Fluoranthene	4,100	nc
Indeno(1,2,3-cd)pyrene	1,200	nc
Pyrene	4,000	nc
Total HPAHs	20,900 J	nc
Benzo(a)pyrene	2,100	nc
Chrysene	2,600	nc
Dibenzo(a,h)anthracene	500	nc
Phenanthrene	2,200	nc
Total PCBs	560	nc

Benzo(a)anthracene	2,600	nc
Benzo(g,h,i)perylene	1,100	nc
Benzyl alcohol	670	na
Chrysene	3,600	nc
Fluoranthene	5,200	nc
Indeno(1,2,3-cd)pyrene	1,200	nc
Mercury	0.63	na
Pyrene	4,400	nc
Total benzofluoranthenes	3,800	nc
Total HPAHs	24,400	nc
Benzo(a)pyrene	2,100	nc
Dibenzo(a,h)anthracene	350	nc
Phenanthrene	1,900	nc
Total PCBs	290	nc
Zinc	435 J	na

Total PCBs	210	18

Fluoranthene	2,500	180
Phenol	740	na

Total PCBs	540	32

Total PCBs	230	38

Fluoranthene	4,500	230

Mercury	0.59	na
Total PCBs	320	14

Acenaphthene	310	18
Benzo(g,h,i)perylene	620	36
Chrysene	2,400	140
Fluoranthene	6,400	370
Fluorene	570	33
Indeno(1,2,3-cd)pyrene	770	45
Phenanthrene	2,600	150
Total HPAHs	19,600	1,140
Total PCBs	230 J	13

Total PCBs	280	15

Phenol	610 J	na

Mercury	0.6	na

Mercury	0.551	na

Mercury	1.55	na
Total PCBs	370	18

2,4-Dimethylphenol	44	na
Benzyl alcohol	64	na
Phenol	573	na

Acenaphthene	550	27
Dibenzofuran	410	20
Fluoranthene	3,600	180
Fluorene	880	44
Phenanthrene	3,500	170

Mercury	1.8	na
Total PCBs	370	23

Fluoranthene	7,800	300
Phenanthrene	3,600	140
Total PCBs	336 J	12.8

Fluoranthene	2,900	nc
Chrysene	2,100	nc
Total HPAHs	12,300	nc
Total PCBs	776	nc

Zinc	427	na

Total PCBs	300	20

Zinc	440	na

Total PCBs	182	nc

Total PCBs	770 J	nc

BBP	100	nc
Total PCBs	270	nc

Chrysene	4,600	220
Fluoranthene	23,000	1,100
Phenanthrene	3,000	140
Total HPAHs	51,000	2,500

Total PCBs	330	19

Total PCBs	660 J	18

Cadmium	7.2	na
Phenol	1,000 J	na

Phenol	450	na

Total PCBs	340	20

Benzo(a)anthracene	2,200	nc
Benzo(a)pyrene	3,200	nc
Benzo(g,h,i)perylene	1,600	nc
Chrysene	3,000	nc
Fluoranthene	4,900	nc
Indeno(1,2,3-cd)pyrene	1,600	nc
Mercury	0.6	na
Pyrene	4,800	nc
Total benzofluoranthenes	4,700	nc
Total HPAHs	26,300	nc
Total PCBs	1,010	nc
Dibenzo(a,h)anthracene	320	nc
Phenanthrene	3,400	nc

2,4-Dimethylphenol	51	na
Mercury	0.451	na

Total PCBs	210	nc

2,4-Dimethylphenol	52 J	na
Mercury	0.491	na

Total PCBs	347 J	18.9

Phenol	600	na

2,4-Dimethylphenol	45	na

Benzo(g,h,i)perylene	560	32
Chrysene	2,100	120
Indeno(1,2,3-cd)pyrene	610	35
Mercury	0.54	na

BEHP	850	81
Lead	573	na
Total PCBs	1,920	183
Arsenic	82.9	na
Zinc	553	na

Arsenic	77.2	na

Arsenic	123	na
Total PCBs	590 J	20

2,4-Dimethylphenol	77	na
Mercury	0.461 J	na
Total PCBs	310 J	15

Total PCBs	267 J	12.6

DR005	BEHP	1,700	74
	BBP	120	5.2
LDW-SS17	BEHP	1,100	64
DUD_20C	Total PCBs	458 J	54
DUD200	4-Methylphenol	770	na
	BEHP	1,500 J	71.4
	BBP	110	5.24
	Total PCBs	280 J	13.3
DUD_12C	Total PCBs	240	20.3
DUD043	BEHP	2,600	124
	BBP	130	6.19
	Total PCBs	570 J	27.1
DR006	BEHP	2,700	99
	BBP	200	7.4
DUD_11C	BEHP	1,150	104
	BBP	124	11.2
DUD_10C	Total PCBs	141.8	14.2
DUD_18C	Total PCBs	1,380 J	134
DUD044	BEHP	1,500	208
	Total PCBs	2,390 J	332
	BBP	42.0	5.83
	HCB	3.80 J	0.528
K-03	Phenol	530 J	na
	Total PCBs	340	13
DUD_9C	Total PCBs	166.7	15.2
DUD031	BEHP	1,100	50
	Total PCBs	572 J	26
DUD045	BEHP	960	56.5
	BBP	110	6.47
	Total PCBs	480 J	28.2
DUD032	Mercury	0.613	na
	BEHP	1,600	60.8
	Total PCBs	935 J	35.6
DR081	BEHP	1,500	84
	Total PCBs	1,473 J	82.8
DUD_8C	Mercury	0.612	na
	Total PCBs	2,970	132
SPI-108	2,4-Dimethylphenol	52	na
	Benzyl alcohol	59	na
	Total PCBs	440 J	28
DUD_17C	Total PCBs	231 J	15.3
DUD033	BEHP	1,300	61.9
	Total PCBs	365 J	17.4
CH1038	Total PCBs	1,400 J	81
DUD204	4-Methylphenol	750	na
	BEHP	2,400 J	100
	BBP	300	12.5
	Total PCBs	292 J	12.2
DUD009	BEHP	1,100	111
	BBP	110	11.1
	Chrysene	1,100	111
	Fluoranthene	3,700	374
	Total HPAHs	10,500 J	1,060
DUD_16C	Total PCBs	700 J	42.2
DR059	BEHP	2,500	92
	BBP	150	5.5
DUD205	4-Methylphenol	1,400	na
	BEHP	2,400 J	85.7
	BBP	160	5.71
	Total PCBs	450 J	16.1
DUD010	BEHP	4,800	nc
	Fluoranthene	3,000	nc
	n-Nitrosodiphenylamine	110	nc
	Benzo(a)anthracene	1,600	nc
	BBP	310	nc
	Chrysene	1,900	nc
	Total benzofluoranthenes	3,250 J	nc
	Total HPAHs	14,390 J	nc
	Total PCBs	860 J	nc
DR010	BEHP	760	54
DUD014	BBP	230	nc

BEHP	1,100	48
Total PCBs	567 J	24.8

BEHP	1,500	53.6
Total PCBs	710 J	25.4

Total PCBs	300 J	19

BBP	350	19
Total PCBs	650	36

Total PCBs	210	13

BEHP	600	49
Total PCBs	326 J	26.5

Total PCBs	790	46

Total PCBs	510	55

Total PCBs	310	21

Fluoranthene	7,400	620
Total HPAHs	13,300 J	1,110
Total PCBs	206	17.2

Total PCBs	212 J	12.9

N

0 250 500 Feet

0 75 150 Meters

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Figure 2-20a. Chemical and Toxicity Test Results Compared to SMS Criteria for FS Baseline Surface Sediment Sampling Locations, RM 0.0 to RM 0.9

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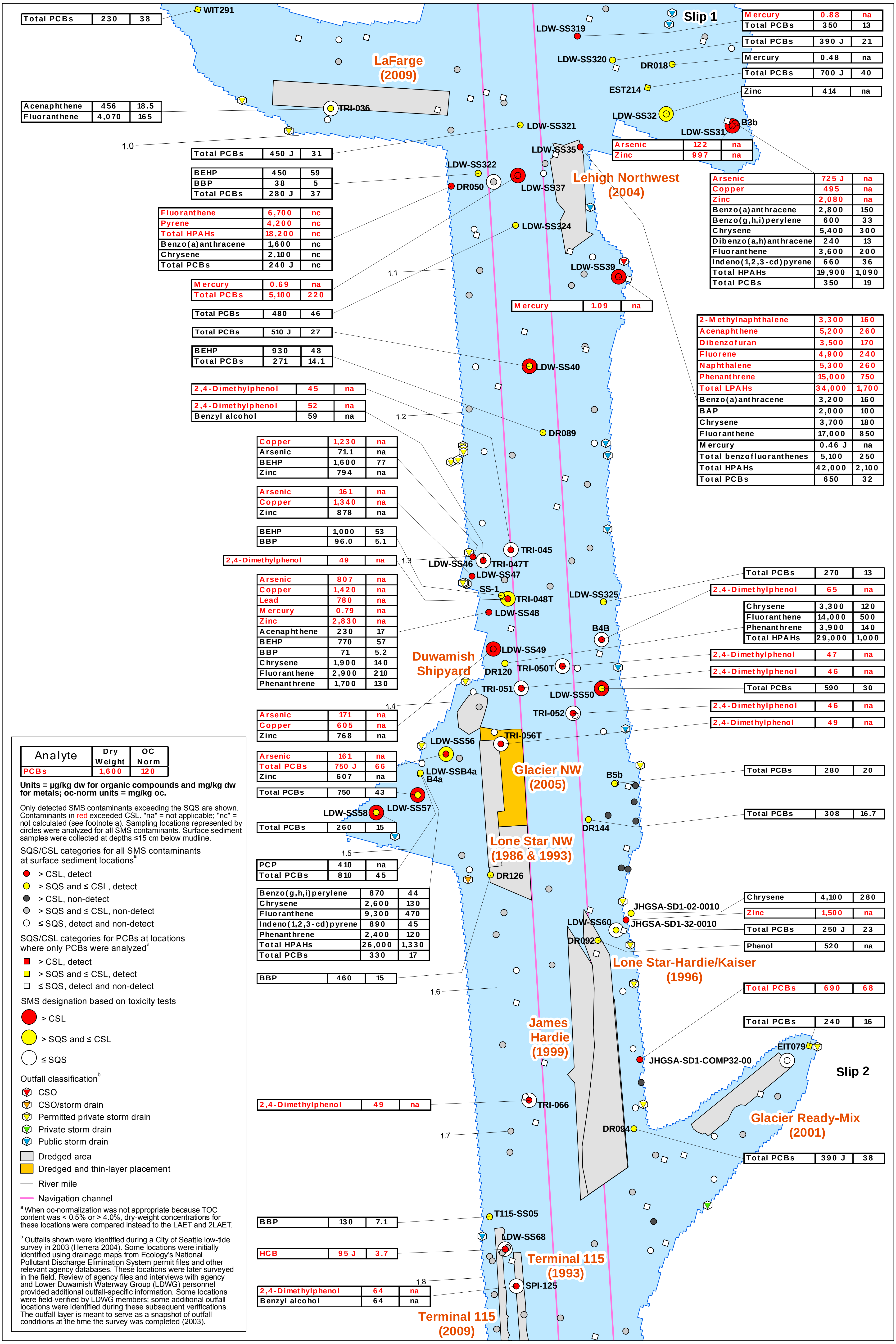
Dredging information provided by AECOM.



Units = µg/kg dw for organic compounds and mg/kg dw for metals; oc-norm units = mg/kg oc.

Only detected SMS contaminants exceeding the SQS are shown. Contaminants in red exceeded CSL. "na" = not applicable; "nc" = not calculated (see footnote a). Sampling locations represented by circles were analyzed for all SMS contaminants. Surface sediment samples were collected at depths ≤15 cm below mudline.

[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and Lower Duwamish Waterway Group (LDWG) personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications. The outfall layer is meant to serve as a snapshot of outfall conditions at the time the survey was completed (2003).

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Figure 2-20b. Chemical and Toxicity Test Results Compared to SMS Criteria for FS Baseline Surface Sediment Sampling Locations, RM 0.9 to RM 1.8

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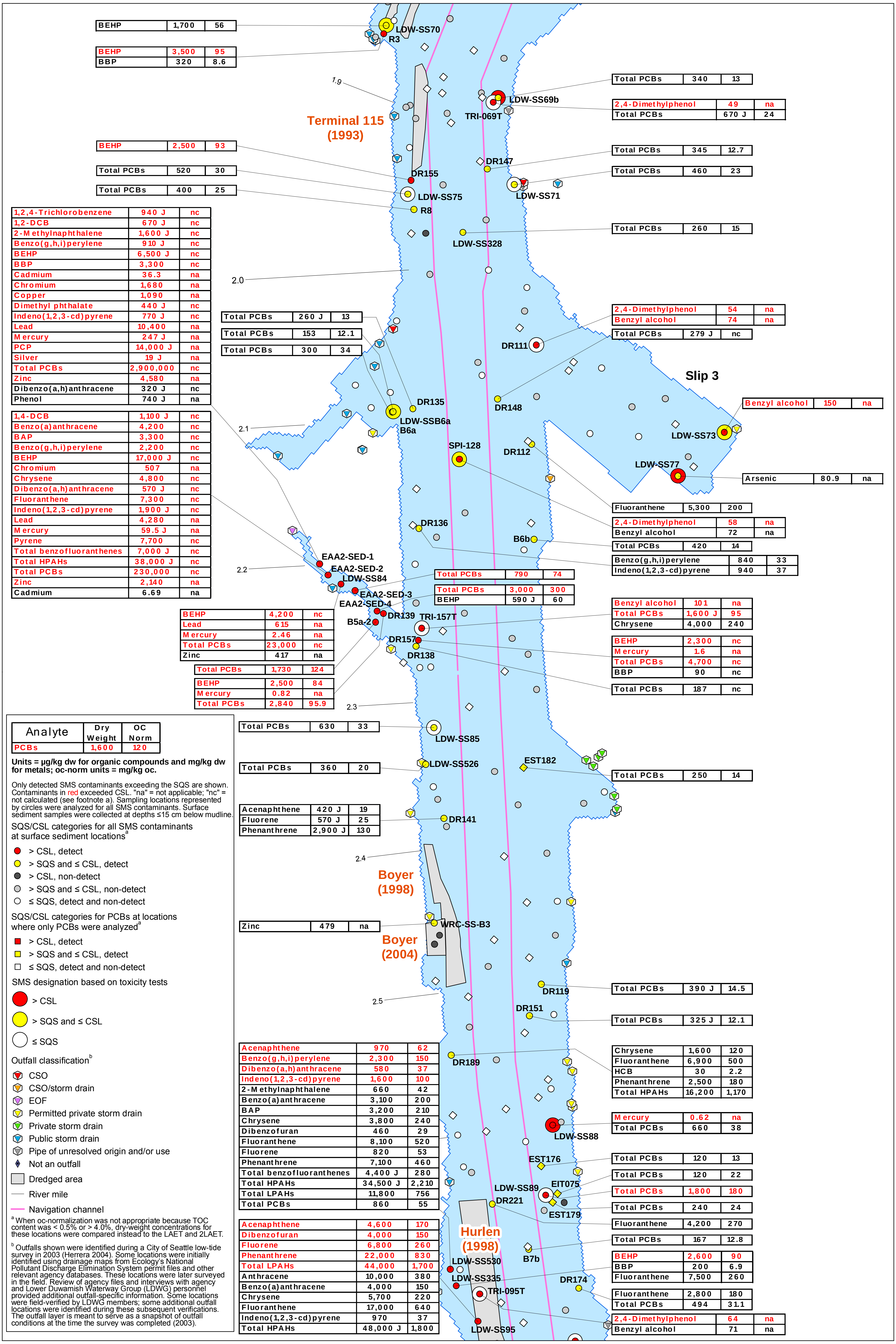
Dredging information provided by AECOM.



BEHP	1,700	56

BEHP	3,500	95
BBP	320	8.6

BEHP	2,500	93

Total PCBs	520	30

Total PCBs	400	25

1,2,4-Trichlorobenzene	940 J	nc
1,2-DCB	670 J	nc
2-Methylnaphthalene	1,600 J	nc
Benzo(g,h,i)perylene	910 J	nc
BEHP	6,500 J	nc
BBP	3,300	nc
Cadmium	36.3	na
Chromium	1,680	na
Copper	1,090	na
Dimethyl phthalate	440 J	nc
Indeno(1,2,3-cd)pyrene	770 J	nc
Lead	10,400	na
Mercury	247 J	na
PCP	14,000 J	na
Silver	19 J	na
Total PCBs	2,900,000	nc
Zinc	4,580	na
Dibenzo(a,h)anthracene	320 J	nc
Phenol	740 J	na

1,4-DCB	1,100 J	nc
Benzo(a)anthracene	4,200	nc
BAP	3,300	nc
Benzo(g,h,i)perylene	2,200	nc
BEHP	17,000 J	nc
Chromium	507	na
Chrysene	4,800	nc
Dibenzo(a,h)anthracene	570 J	nc
Fluoranthene	7,300	nc
Indeno(1,2,3-cd)pyrene	1,900 J	nc
Lead	4,280	na
Mercury	59.5 J	na
Pyrene	7,700	nc
Total benzofluoranthenes	7,000 J	nc
Total HPAHs	38,000 J	nc
Total PCBs	230,000	nc
Zinc	2,140	na
Cadmium	6.69	na

Total PCBs	260 J	13

Total PCBs	153	12.1

Total PCBs	300	34

BEHP	4,200	nc
Lead	615	na
Mercury	2.46	na
Total PCBs	23,000	nc
Zinc	417	na

Total PCBs	1,730	124

BEHP	2,500	84
Mercury	0.82	na
Total PCBs	2,840	95.9

Total PCBs	790	74

Total PCBs	3,000	300
BEHP	590 J	60

Total PCBs	630	33

Total PCBs	360	20

Acenaphthene	420 J	19
Fluorene	570 J	25
Phenanthrene	2,900 J	130

Zinc	479	na

Acenaphthene	970	62
Benzo(g,h,i)perylene	2,300	150
Dibenzo(a,h)anthracene	580	37
Indeno(1,2,3-cd)pyrene	1,600	100
2-Methylnaphthalene	660	42
Benzo(a)anthracene	3,100	200
BAP	3,200	210
Chrysene	3,800	240
Dibenzofuran	460	29
Fluoranthene	8,100	520
Fluorene	820	53
Phenanthrene	7,100	460
Total benzofluoranthenes	4,400 J	280
Total HPAHs	34,500 J	2,210
Total LPAHs	11,800	756
Total PCBs	860	55

Acenaphthene	4,600	170
Dibenzofuran	4,000	150
Fluorene	6,800	260
Phenanthrene	22,000	830
Total LPAHs	44,000	1,700
Anthracene	10,000	380
Benzo(a)anthracene	4,000	150
Chrysene	5,700	220
Fluoranthene	17,000	640
Indeno(1,2,3-cd)pyrene	970	37
Total HPAHs	48,000 J	1,800

Total PCBs	340	13

2,4-Dimethylphenol	49	na
Total PCBs	670 J	24

Total PCBs	345	12.7

Total PCBs	460	23

Total PCBs	260	15

2,4-Dimethylphenol	54	na
Benzyl alcohol	74	na

Total PCBs	279 J	nc

Benzyl alcohol	150	na

Arsenic	80.9	na

Fluoranthene	5,300	200

2,4-Dimethylphenol	58	na
Benzyl alcohol	72	na

Total PCBs	420	14

Benzo(g,h,i)perylene	840	33
Indeno(1,2,3-cd)pyrene	940	37

Benzyl alcohol	101	na
Total PCBs	1,600 J	95
Chrysene	4,000	240

BEHP	2,300	nc
Mercury	1.6	na
Total PCBs	4,700	nc
BBP	90	nc

Total PCBs	187	nc

Total PCBs	250	14

Total PCBs	390 J	14.5

Total PCBs	325 J	12.1

Chrysene	1,600	120
Fluoranthene	6,900	500
HCB	30	2.2
Phenanthrene	2,500	180
Total HPAHs	16,200	1,170

Mercury	0.62	na
Total PCBs	660	38

Total PCBs	120	13

Total PCBs	120	22

Total PCBs	1,800	180

Total PCBs	240	24

Fluoranthene	4,200	270

Total PCBs	167	12.8

BEHP	2,600	90
BBP	200	6.9
Fluoranthene	7,500	260

Fluoranthene	2,800	180
Total PCBs	494	31.1

2,4-Dimethylphenol	64	na
Benzyl alcohol	71	na

Analyte	Dry Weight	OC Norm
PCBs	1,600	120

Units = µg/kg dw for organic compounds and mg/kg dw for metals; oc-norm units = mg/kg oc.

Only detected SMS contaminants exceeding the SQS are shown. Contaminants in red exceeded CSL. "na" = not applicable; "nc" = not calculated (see footnote a). Sampling locations represented by circles were analyzed for all SMS contaminants. Surface sediment samples were collected at depths ≤15 cm below mudline.

SQS/CSL categories for all SMS contaminants at surface sediment locations[a]

- ● > CSL, detect
- ● > SQS and ≤ CSL, detect
- ● > CSL, non-detect
- ● > SQS and ≤ CSL, non-detect
- ○ ≤ SQS, detect and non-detect

SQS/CSL categories for PCBs at locations where only PCBs were analyzed[a]

- ■ > CSL, detect
- ■ > SQS and ≤ CSL, detect
- □ ≤ SQS, detect and non-detect

SMS designation based on toxicity tests

- ● > CSL
- ● > SQS and ≤ CSL
- ○ ≤ SQS

Outfall classification[b]

- ▼ CSO
- ▼ CSO/storm drain
- ▼ EOF
- ▼ Permitted private storm drain
- ▼ Private storm drain
- ▼ Public storm drain
- ▼ Pipe of unresolved origin and/or use
- ◆ Not an outfall
- ▨ Dredged area
- — River mile
- — Navigation channel

[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

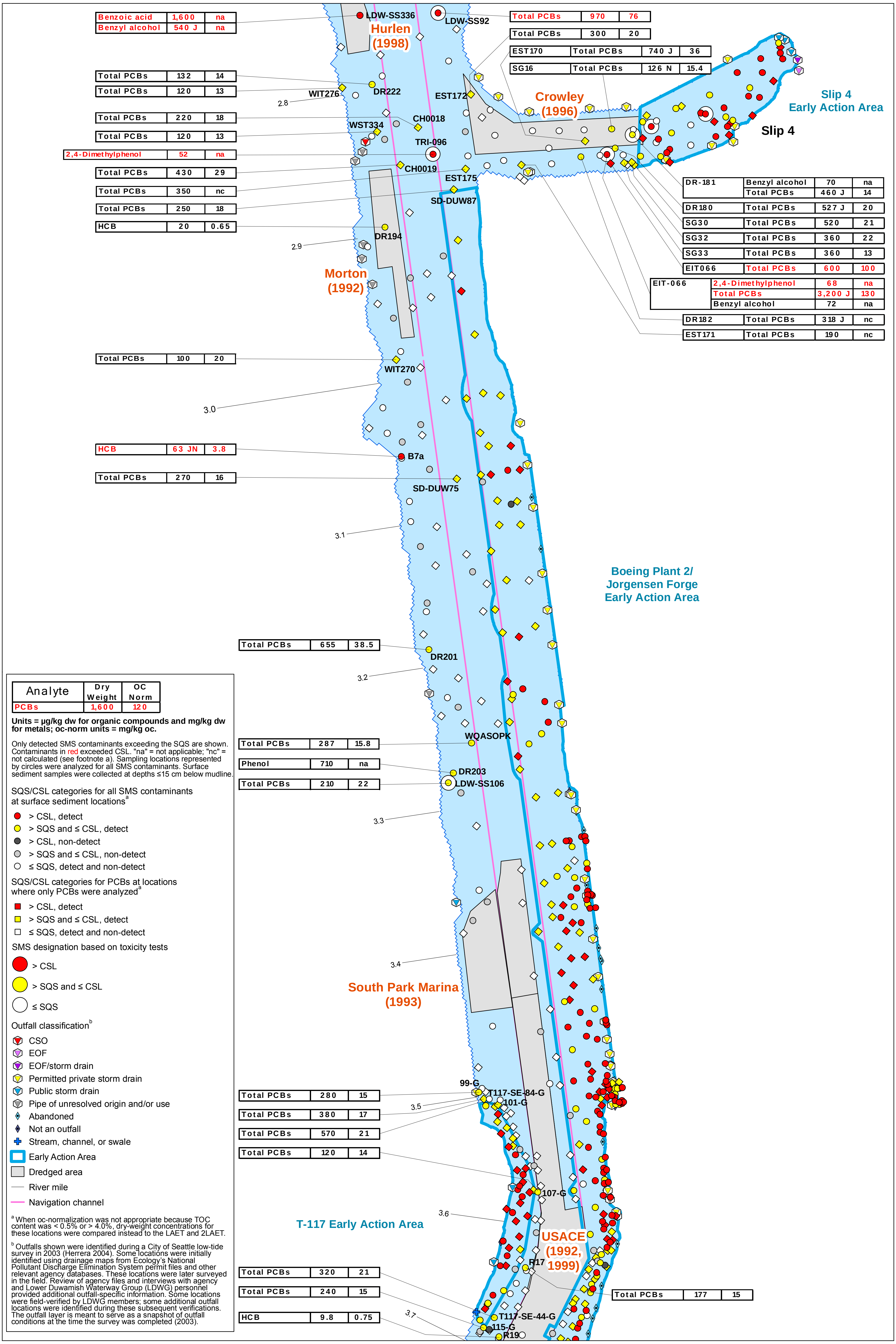
[b] Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and Lower Duwamish Waterway Group (LDWG) personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications. The outfall layer is meant to serve as a snapshot of outfall conditions at the time the survey was completed (2003).

Figure 2-20c. Chemical and Toxicity Test Results Compared to SMS Criteria for FS Baseline Surface Sediment Sampling Locations, RM 1.8 to RM 2.7

Lower Duwamish Waterway Final Feasibility Study

Prepared by innamm, 10/31/2012; L:\Lower Duwamish FS\FS_Final_GISOct2012\2012-10-15 LDW FS WW GIS Maps and Data\Fig 2-20c 2896 SMS with tables1.mxd

Dredging information provided by AECOM.



Units = µg/kg dw for organic compounds and mg/kg dw for metals; oc-norm units = mg/kg oc.

Only detected SMS contaminants exceeding the SQS are shown. Contaminants in red exceeded CSL. "na" = not applicable; "nc" = not calculated (see footnote a). Sampling locations represented by circles were analyzed for all SMS contaminants. Surface sediment samples were collected at depths ≤15 cm below mudline.

[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and Lower Duwamish Waterway Group (LDWG) personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications. The outfall layer is meant to serve as a snapshot of outfall conditions at the time the survey was completed (2003).

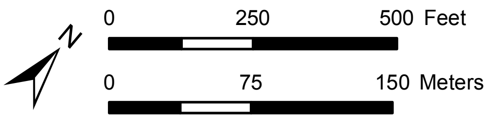


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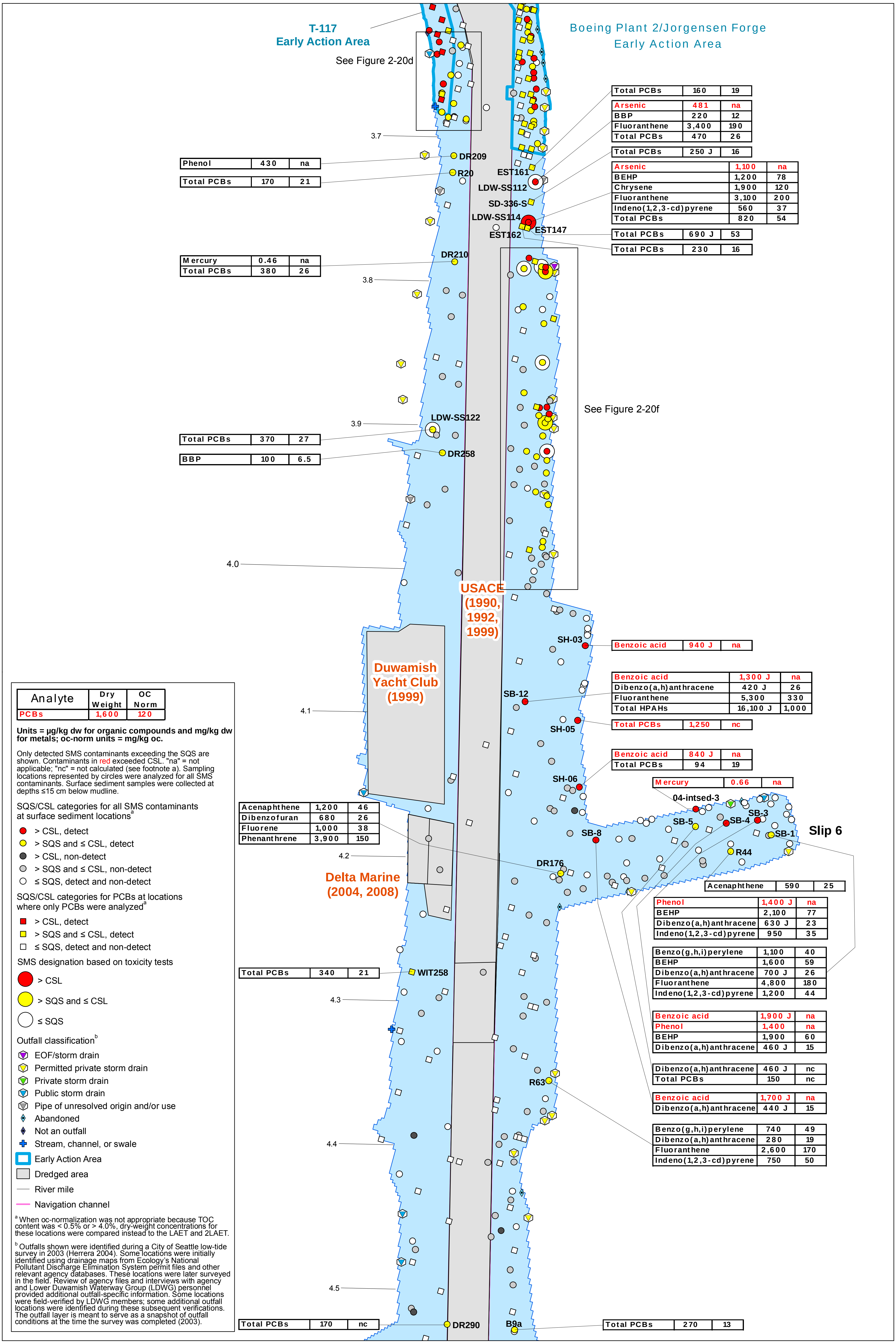
Figure 2-20d. Chemical and Toxicity Test Results Compared to SMS Criteria for FS Baseline Surface Sediment Sampling Locations, RM 2.8 to RM 3.7

Lower Duwamish Waterway Final Feasibility Study

Prepared by inmanm, 10/31/2012; L:\Lower Duwamish FS\FS_Final_GISOct2012\2012-10-15 LDW FS WW GIS Maps and Data\Fig 2-20d 2896 SMS with tables1.mxd

Dredging information provided by AECOM.



Analyte	Dry Weight	OC Norm
PCBs	1,600	120

Units = µg/kg dw for organic compounds and mg/kg dw for metals; oc-norm units = mg/kg oc.

Only detected SMS contaminants exceeding the SQS are shown. Contaminants in red exceeded CSL. "na" = not applicable; "nc" = not calculated (see footnote a). Sampling locations represented by circles were analyzed for all SMS contaminants. Surface sediment samples were collected at depths ≤15 cm below mudline.

SQS/CSL categories for all SMS contaminants at surface sediment locations[a]

- ● > CSL, detect
- ● > SQS and ≤ CSL, detect
- ● > CSL, non-detect
- ● > SQS and ≤ CSL, non-detect
- ○ ≤ SQS, detect and non-detect

SQS/CSL categories for PCBs at locations where only PCBs were analyzed[a]

- ■ > CSL, detect
- ■ > SQS and ≤ CSL, detect
- ☐ ≤ SQS, detect and non-detect

SMS designation based on toxicity tests

- ● > CSL
- ● > SQS and ≤ CSL
- ○ ≤ SQS

Outfall classification[b]

- ▼ EOF/storm drain
- ▼ Permitted private storm drain
- ▼ Private storm drain
- ▼ Public storm drain
- ▼ Pipe of unresolved origin and/or use
- ◆ Abandoned
- ◆ Not an outfall
- ✚ Stream, channel, or swale
- ☐ Early Action Area
- ▨ Dredged area
- — River mile
- — Navigation channel

[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and Lower Duwamish Waterway Group (LDWG) personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications. The outfall layer is meant to serve as a snapshot of outfall conditions at the time the survey was completed (2003).

Phenol	430	na

Total PCBs	170	21

Mercury	0.46	na
Total PCBs	380	26

Total PCBs	370	27

BBP	100	6.5

Total PCBs	160	19

Arsenic	481	na
BBP	220	12
Fluoranthene	3,400	190
Total PCBs	470	26

Total PCBs	250 J	16

Arsenic	1,100	na
BEHP	1,200	78
Chrysene	1,900	120
Fluoranthene	3,100	200
Indeno(1,2,3-cd)pyrene	560	37
Total PCBs	820	54

Total PCBs	690 J	53

Total PCBs	230	16

Benzoic acid	940 J	na

Benzoic acid	1,300 J	na
Dibenzo(a,h)anthracene	420 J	26
Fluoranthene	5,300	330
Total HPAHs	16,100 J	1,000

Total PCBs	1,250	nc

Benzoic acid	840 J	na
Total PCBs	94	19

Mercury	0.66	na

Acenaphthene	1,200	46
Dibenzofuran	680	26
Fluorene	1,000	38
Phenanthrene	3,900	150

Acenaphthene	590	25

Phenol	1,400 J	na
BEHP	2,100	77
Dibenzo(a,h)anthracene	630 J	23
Indeno(1,2,3-cd)pyrene	950	35

Benzo(g,h,i)perylene	1,100	40
BEHP	1,600	59
Dibenzo(a,h)anthracene	700 J	26
Fluoranthene	4,800	180
Indeno(1,2,3-cd)pyrene	1,200	44

Benzoic acid	1,900 J	na
Phenol	1,400	na
BEHP	1,900	60
Dibenzo(a,h)anthracene	460 J	15

Dibenzo(a,h)anthracene	460 J	nc
Total PCBs	150	nc

Benzoic acid	1,700 J	na
Dibenzo(a,h)anthracene	440 J	15

Benzo(g,h,i)perylene	740	49
Dibenzo(a,h)anthracene	280	19
Fluoranthene	2,600	170
Indeno(1,2,3-cd)pyrene	750	50

Total PCBs	340	21

Total PCBs	170	nc

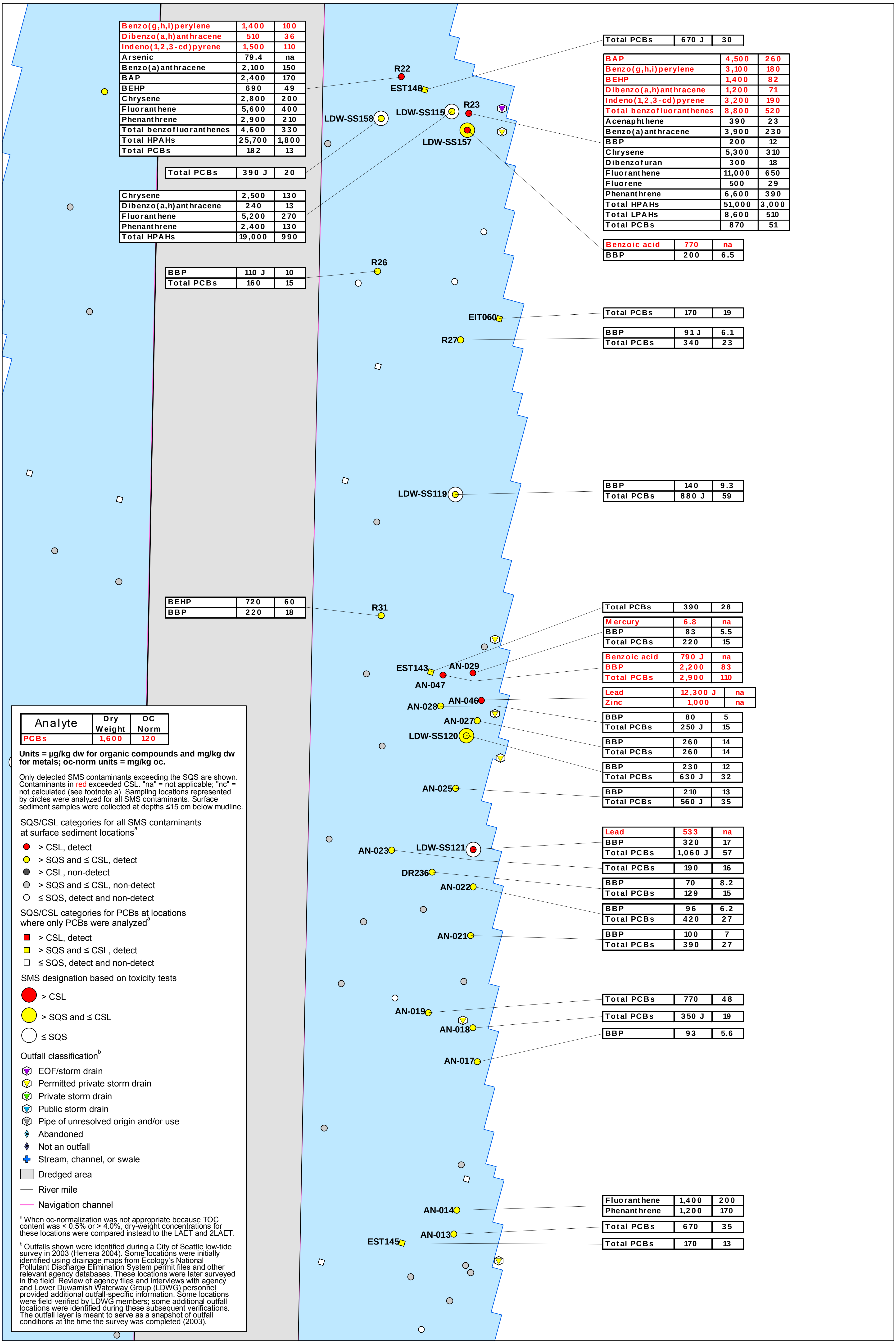
Total PCBs	270	13

Figure 2-20e. Chemical and Toxicity Test Results Compared to SMS Criteria for FS Baseline Surface Sediment Sampling Locations, RM 3.7 to RM 4.5

Lower Duwamish Waterway Final Feasibility Study

Prepared by inmanm, 10/31/2012; L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\2012-10-15 LDW FS WW GIS Maps and Data\Fig 2-20e 2896 SMS with tables1.mxd

Dredging information provided by AECOM.



Benzo(g,h,i)perylene	1,400	100
Dibenzo(a,h)anthracene	510	36
Indeno(1,2,3-cd)pyrene	1,500	110
Arsenic	79.4	na
Benzo(a)anthracene	2,100	150
BAP	2,400	170
BEHP	690	49
Chrysene	2,800	200
Fluoranthene	5,600	400
Phenanthrene	2,900	210
Total benzofluoranthenes	4,600	330
Total HPAHs	25,700	1,800
Total PCBs	182	13

Total PCBs	390 J	20

Chrysene	2,500	130
Dibenzo(a,h)anthracene	240	13
Fluoranthene	5,200	270
Phenanthrene	2,400	130
Total HPAHs	19,000	990

BBP	110 J	10
Total PCBs	160	15

BEHP	720	60
BBP	220	18

Total PCBs	670 J	30

BAP	4,500	260
Benzo(g,h,i)perylene	3,100	180
BEHP	1,400	82
Dibenzo(a,h)anthracene	1,200	71
Indeno(1,2,3-cd)pyrene	3,200	190
Total benzofluoranthenes	8,800	520
Acenaphthene	390	23
Benzo(a)anthracene	3,900	230
BBP	200	12
Chrysene	5,300	310
Dibenzofuran	300	18
Fluoranthene	11,000	650
Fluorene	500	29
Phenanthrene	6,600	390
Total HPAHs	51,000	3,000
Total LPAHs	8,600	510
Total PCBs	870	51

Benzoic acid	770	na
BBP	200	6.5

Total PCBs	170	19

BBP	91 J	6.1
Total PCBs	340	23

BBP	140	9.3
Total PCBs	880 J	59

Total PCBs	390	28

Mercury	6.8	na
BBP	83	5.5
Total PCBs	220	15

Benzoic acid	790 J	na
BBP	2,200	83
Total PCBs	2,900	110

Lead	12,300 J	na
Zinc	1,000	na

BBP	80	5
Total PCBs	250 J	15

BBP	260	14
Total PCBs	260	14

BBP	230	12
Total PCBs	630 J	32

BBP	210	13
Total PCBs	560 J	35

Lead	533	na
BBP	320	17
Total PCBs	1,060 J	57

Total PCBs	190	16

BBP	70	8.2
Total PCBs	129	15

BBP	96	6.2
Total PCBs	420	27

BBP	100	7
Total PCBs	390	27

Total PCBs	770	48

Total PCBs	350 J	19

BBP	93	5.6

Fluoranthene	1,400	200
Phenanthrene	1,200	170

Total PCBs	670	35

Total PCBs	170	13

Analyte	Dry Weight	OC Norm
PCBs	1,600	120

Units = µg/kg dw for organic compounds and mg/kg dw for metals; oc-norm units = mg/kg oc.

Only detected SMS contaminants exceeding the SQS are shown. Contaminants in red exceeded CSL. "na" = not applicable; "nc" = not calculated (see footnote a). Sampling locations represented by circles were analyzed for all SMS contaminants. Surface sediment samples were collected at depths ≤15 cm below mudline.

SQS/CSL categories for all SMS contaminants at surface sediment locations[a]

- ● > CSL, detect
- ● > SQS and ≤ CSL, detect
- ● > CSL, non-detect
- ● > SQS and ≤ CSL, non-detect
- ○ ≤ SQS, detect and non-detect

SQS/CSL categories for PCBs at locations where only PCBs were analyzed[a]

- ■ > CSL, detect
- ■ > SQS and ≤ CSL, detect
- □ ≤ SQS, detect and non-detect

SMS designation based on toxicity tests

- ● > CSL
- ● > SQS and ≤ CSL
- ○ ≤ SQS

Outfall classification[b]

- ⬟ EOF/storm drain
- ⬟ Permitted private storm drain
- ⬟ Private storm drain
- ⬟ Public storm drain
- ⬟ Pipe of unresolved origin and/or use
- ◆ Abandoned
- ◆ Not an outfall
- ✚ Stream, channel, or swale
- ▢ Dredged area
- — River mile
- — Navigation channel

[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and Lower Duwamish Waterway Group (LDWG) personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications. The outfall layer is meant to serve as a snapshot of outfall conditions at the time the survey was completed (2003).

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Figure 2-20f. Chemical and Toxicity Test Results Compared to SMS Criteria for FS Baseline Surface Sediment Sampling Locations, RM 3.8 to RM 4.0

Lower Duwamish Waterway Final Feasibility Study

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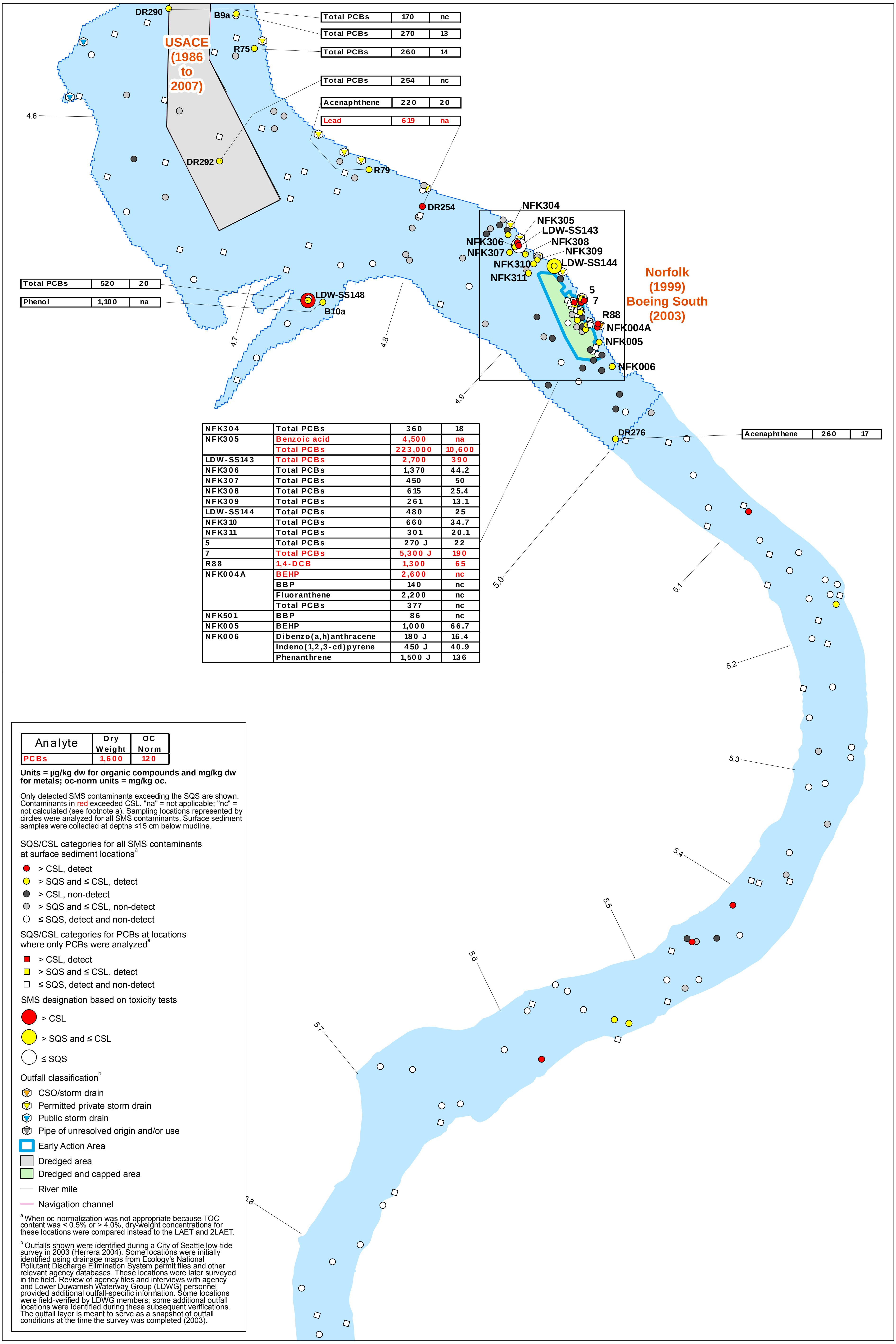
Dredging information provided by AECOM.



Total PCBs	170	nc
Total PCBs	270	13
Total PCBs	260	14
Total PCBs	254	nc
Acenaphthene	220	20
Lead	619	na

Total PCBs	520	20
Phenol	1,100	na

Acenaphthene	260	17

NFK304	Total PCBs	360	18
NFK305	Benzoic acid	4,500	na
	Total PCBs	223,000	10,600
LDW-SS143	Total PCBs	2,700	390
NFK306	Total PCBs	1,370	44.2
NFK307	Total PCBs	450	50
NFK308	Total PCBs	615	25.4
NFK309	Total PCBs	261	13.1
LDW-SS144	Total PCBs	480	25
NFK310	Total PCBs	660	34.7
NFK311	Total PCBs	301	20.1
5	Total PCBs	270 J	22
7	Total PCBs	5,300 J	190
R88	1,4-DCB	1,300	65
NFK004A	BEHP	2,600	nc
	BBP	140	nc
	Fluoranthene	2,200	nc
	Total PCBs	377	nc
NFK501	BBP	86	nc
NFK005	BEHP	1,000	66.7
NFK006	Dibenzo(a,h)anthracene	180 J	16.4
	Indeno(1,2,3-cd)pyrene	450 J	40.9
	Phenanthrene	1,500 J	136

Analyte	Dry Weight	OC Norm
PCBs	1,600	120

Units = μg/kg dw for organic compounds and mg/kg dw for metals; oc-norm units = mg/kg oc.

Only detected SMS contaminants exceeding the SQS are shown. Contaminants in red exceeded CSL. "na" = not applicable; "nc" = not calculated (see footnote a). Sampling locations represented by circles were analyzed for all SMS contaminants. Surface sediment samples were collected at depths ≤15 cm below mudline.

SQS/CSL categories for all SMS contaminants at surface sediment locations[a]

- ● > CSL, detect
- ● > SQS and ≤ CSL, detect
- ● > CSL, non-detect
- ● > SQS and ≤ CSL, non-detect
- ○ ≤ SQS, detect and non-detect

SQS/CSL categories for PCBs at locations where only PCBs were analyzed[a]

- ■ > CSL, detect
- ■ > SQS and ≤ CSL, detect
- □ ≤ SQS, detect and non-detect

SMS designation based on toxicity tests

- ● > CSL
- ● > SQS and ≤ CSL
- ○ ≤ SQS

Outfall classification[b]

- ⬡ CSO/storm drain
- ⬡ Permitted private storm drain
- ⬡ Public storm drain
- ⬡ Pipe of unresolved origin and/or use
- ▢ Early Action Area
- ▨ Dredged area
- 🟩 Dredged and capped area
- — River mile
- — Navigation channel

[a] When oc-normalization was not appropriate because TOC content was < 0.5% or > 4.0%, dry-weight concentrations for these locations were compared instead to the LAET and 2LAET.

[b] Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and Lower Duwamish Waterway Group (LDWG) personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications. The outfall layer is meant to serve as a snapshot of outfall conditions at the time the survey was completed (2003).

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N

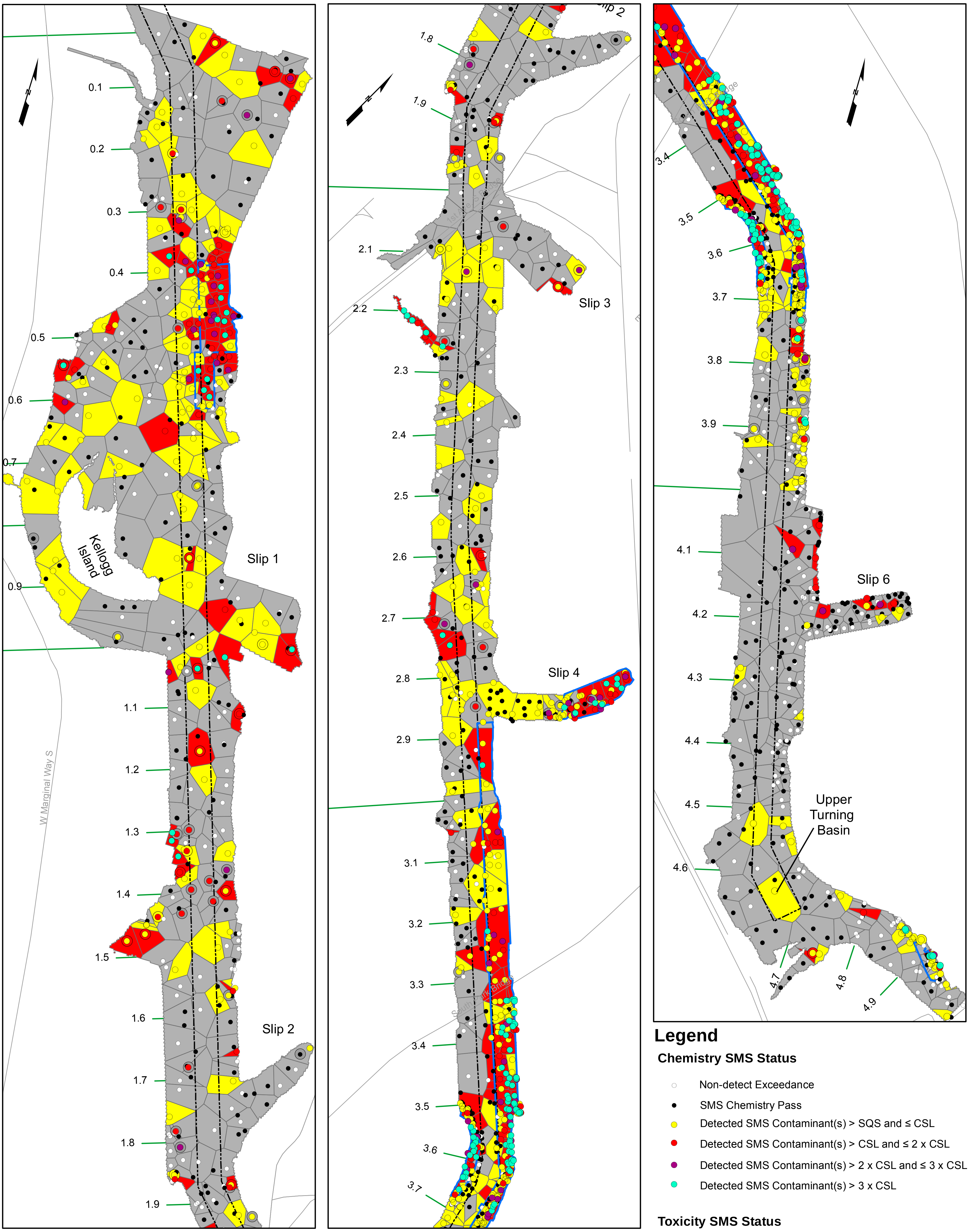
0 250 500 Feet

0 75 150 Meters

Figure 2-20g. Chemical and Toxicity Test Results Compared to SMS Criteria for FS Baseline Surface Sediment Sampling Locations, RM 4.5 to RM 5.0

Lower Duwamish Waterway Final Feasibility Study

Dredging information provided by AECOM.



Legend

Chemistry SMS Status

- ○ Non-detect Exceedance
- ● SMS Chemistry Pass
- ● Detected SMS Contaminant(s) > SQS and ≤ CSL
- ● Detected SMS Contaminant(s) > CSL and ≤ 2 x CSL
- ● Detected SMS Contaminant(s) > 2 x CSL and ≤ 3 x CSL
- ● Detected SMS Contaminant(s) > 3 x CSL

Toxicity SMS Status

- ● Pass
- ● > SQS and ≤ CSL
- ● > CSL

Thiessen Polygon SMS Status

- ⬜ Pass
- 🟨 > SQS and ≤ CSL
- 🟥 > CSL

Notes:
1. Chemistry exceedances address all detected SMS contaminant(s), including total PCBs and arsenic.
2. The sampling dates of the surface sediment data range from 1991 to 2010.
3. Contaminant exceedance data from FS baseline dataset dated April 28, 2010.
4. Thiessen polygon SMS status is assigned to match that for the highest exceedance status for any contaminant for any point within that polygon. If a toxicity sample is co-located with a chemistry sample, the toxicity data override the chemistry results for that polygon.

- —— Road
- -·-·- Navigation Channel
- —— River Mile Marker
- ▭ Early Action Area

0 200 400 800 Feet

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Final Feasibility Study
60150279-14.34

Interpolation by Thiessen Polygon of SMS Status in Surface Sediment

DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	**FIGURE 2-21**

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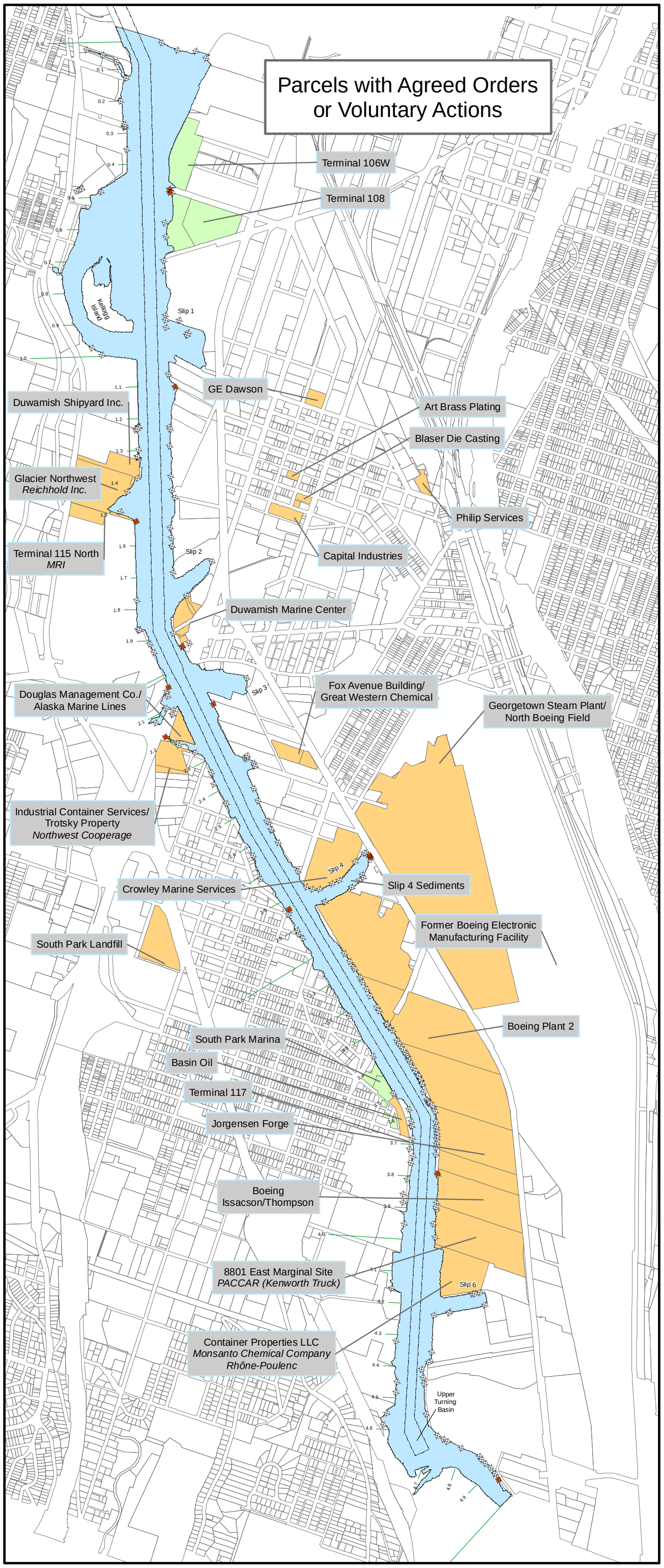

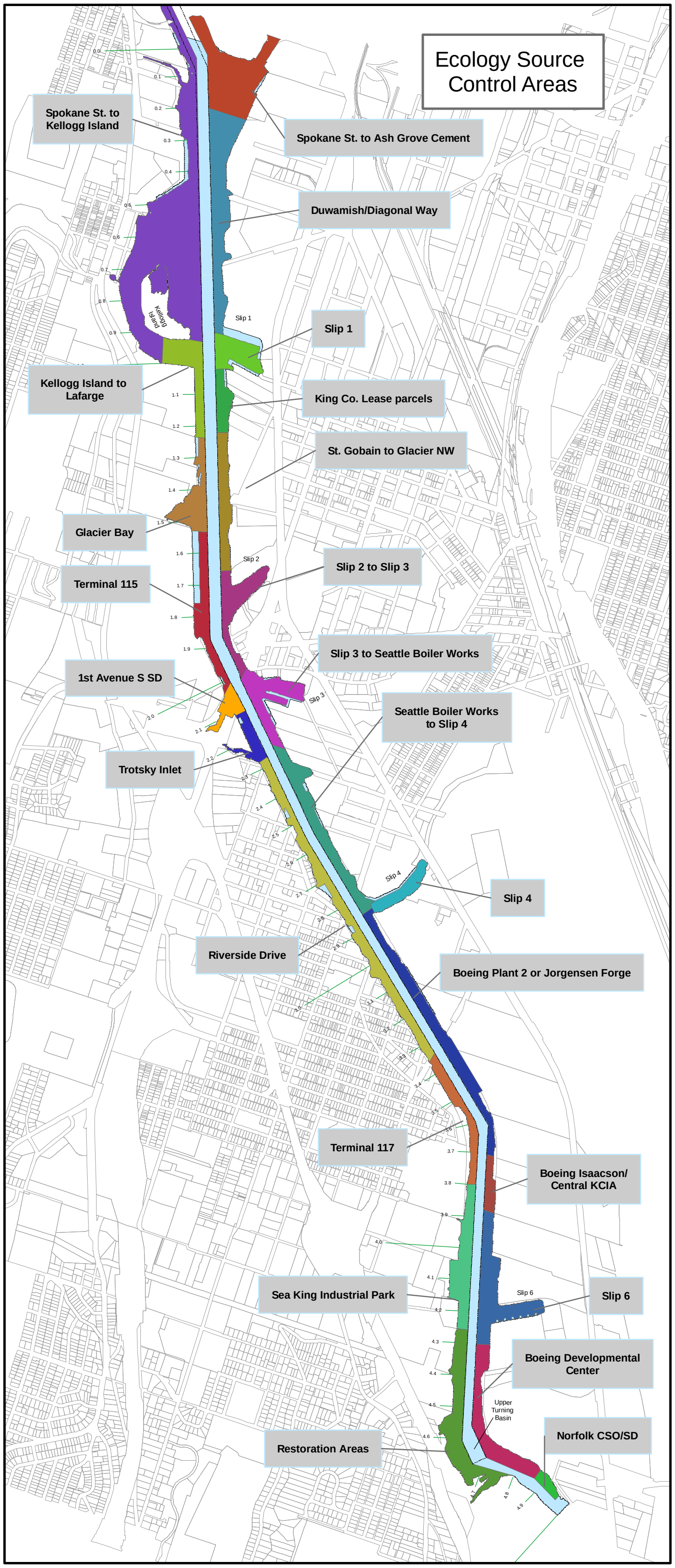

Notes:
1. King County Assessor parcel data received from King County on Sept. 22, 2004.
2. Ecology's source control areas were last updated in Sept. 2010.
3. *Italics*= historical operator.
4. Parcels in first panel are under, or are in negotiation for, either MTCA orders or EPA CERCLA or RCRA orders. They include Agreed Orders, Removal Orders, Enforcement Orders, and Consent Decrees.
5. CERCLA= Comprehensive Environmental Response, Compensation, and Liability Act; CSO= combined sewer overflow; EOF= Emergency Overflow; MTCA= Model Toxics Control Act; RCRA= Resource Conservation and Recovery Act; SD= storm drain.

Legend

Owner or Site Name — Glacier Northwest
Historical Operator — *Reichhold Inc.*

- 🟩 Site Investigation or Voluntary Action
- 🟧 MTCA, RCRA, or CERCLA Agreed Order Parcel
- 🟥 Ecology Source Control Area (color varies by area)
- 🟦 Lower Duwamish Waterway
- ☐ Parcel
- Navigation Channel
- River Mile Marker
- ⊕ CSO/EOF Location
- ⊕ Other Outfall Location

Feet
0 500 1,000 2,000

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Agreed Orders/Voluntary Actions and Ecology Source Control Areas

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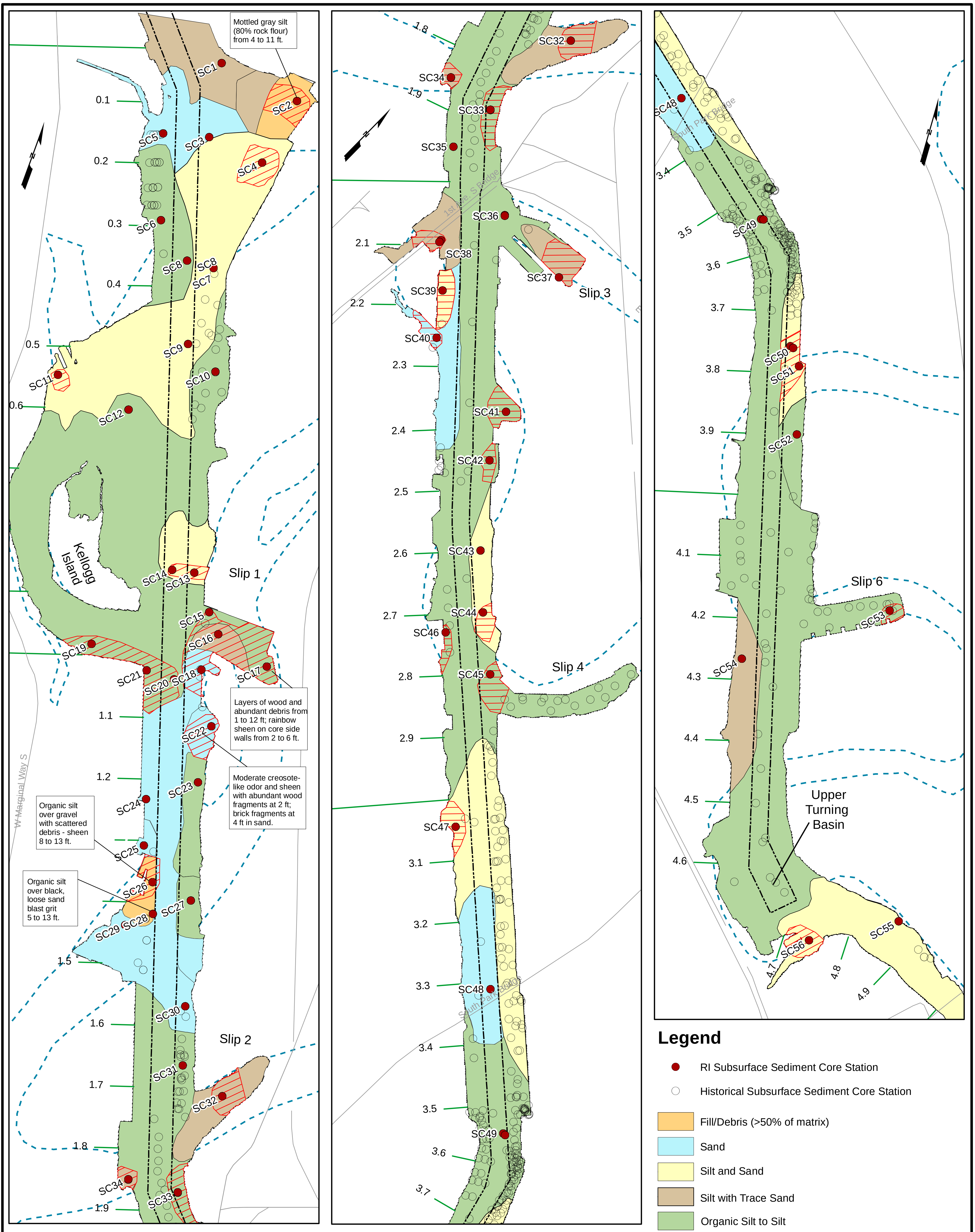
FIGURE 2-22



Mottled gray silt (80% rock flour) from 4 to 11 ft.

Layers of wood and abundant debris from 1 to 12 ft; rainbow sheen on core side walls from 2 to 6 ft.

Moderate creosote-like odor and sheen with abundant wood fragments at 2 ft; brick fragments at 4 ft in sand.

Organic silt over gravel with scattered debris - sheen 8 to 13 ft.

Organic silt over black, loose sand blast grit 5 to 13 ft.

Legend

- ● RI Subsurface Sediment Core Station
- ○ Historical Subsurface Sediment Core Station
- 🟧 Fill/Debris (>50% of matrix)
- 🟦 Sand
- 🟨 Silt and Sand
- 🟫 Silt with Trace Sand
- 🟩 Organic Silt to Silt
- ▨ Debris, Hydrocarbon-like Odor/Sheen or Gravel
- ⬚ Pre-1916 Duwamish River
- ─ Road
- -·-· Navigation Channel
- ─ River Mile Marker

Notes:
1. Distribution of debris and subsurface facies based on 2006 core logs, percent fines, physical data, and bathymetry. Facies represent common lithology across an interval of 4-ft depth. Groupings based on visual USC soil classifications (> 50% of matrix), ASTM grain size results, and Atterberg Limit results.
2. All contacts are inferred, and spatial extents are very approximate.
3. Depths in recovered feet below mudline.
4. Debris layer based on visual observations in cores at any depth and visual interpolation between cores.
5. See Table 2-8 for description of debris/sheen identified in RI cores. Most cores identified with hatching contain both debris and odor/sheen.

Feet
0 200 400 800

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Generalized Subsurface Sediment Properties and Debris

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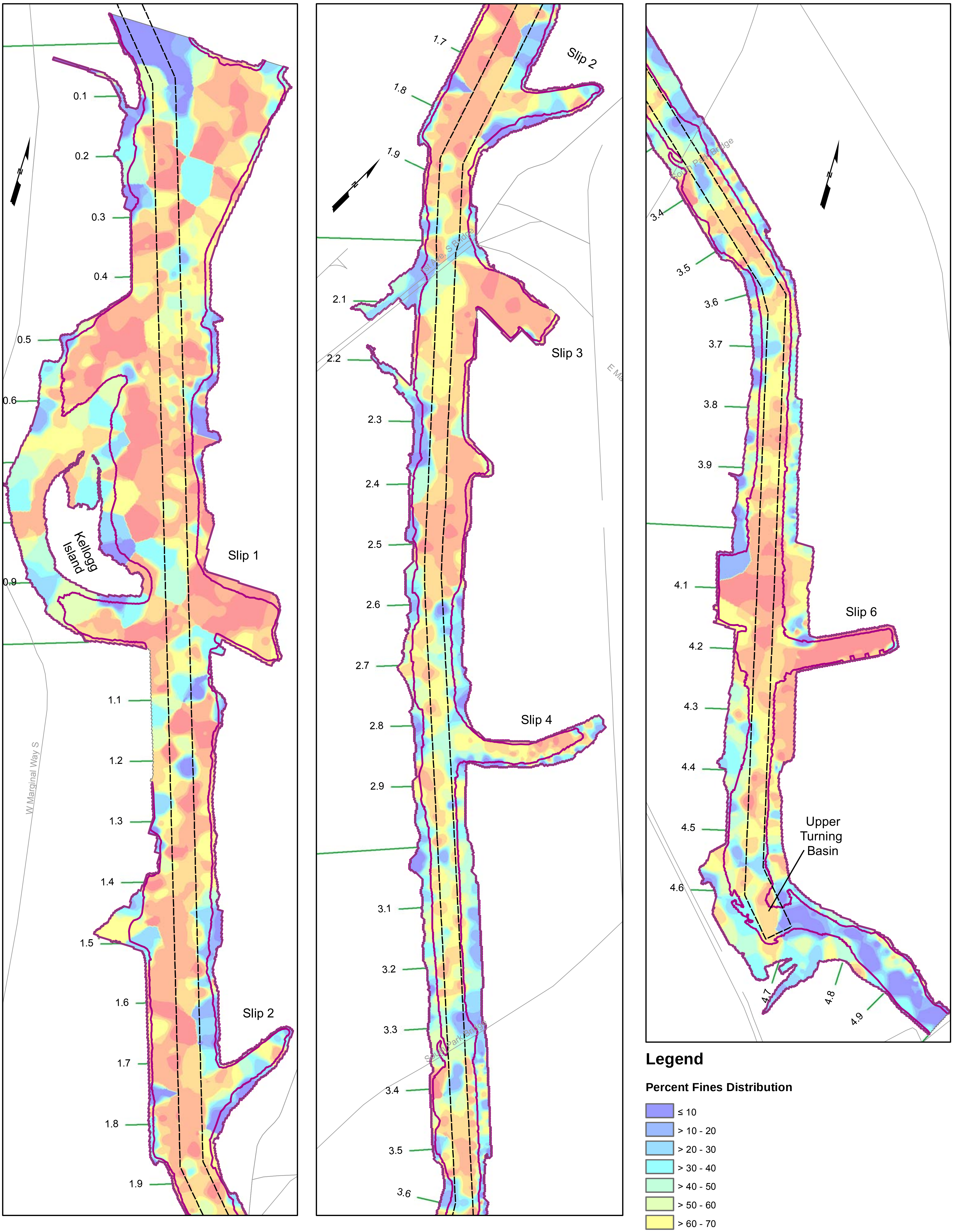
FIGURE 2-23

L:\Lower Duwamish FS\IFS_Final_GISOct2012\IFS_GIS_MXDs_Oct12\Section 2\Fig2-23AnthroSubSurf.mxd



Legend

Percent Fines Distribution

- ■ ≤ 10
- ■ > 10 - 20
- ■ > 20 - 30
- ■ > 30 - 40
- ■ > 40 - 50
- ■ > 50 - 60
- ■ > 60 - 70
- ■ > 70 - 80
- ■ > 80 - 90
- ■ > 90

- ▭ Intertidal Area
- — Road
- - - Navigation Channel
- — River Mile Marker

Notes:
1. Percent fines data from FS baseline dataset dated April 28, 2010.
2. Percent fines is the sum of silt and clay size particle fractions.
3. Grid interpolated using the following parameters: Power 5, nearest neighbors 10/1, search radius 150x150 ft.

0 200 400 800 Feet

L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\FS_GIS_MXDs_Oct12\Section 2\Figure2-24PercentFines.mxd

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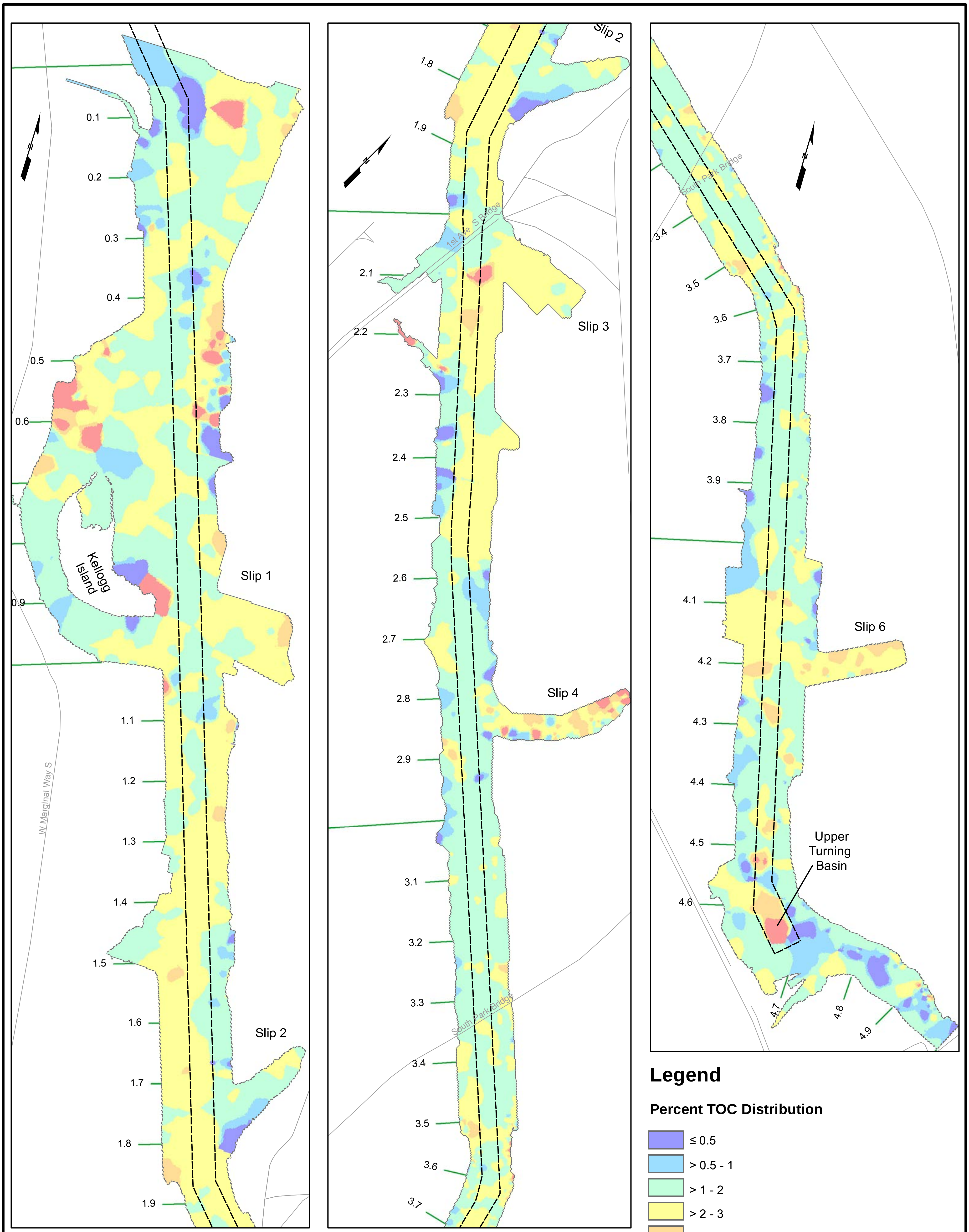
Distribution of Fine-Grained Surface Sediments

FIGURE 2-24



Legend

Percent TOC Distribution

🟪 ≤ 0.5
🟦 > 0.5 - 1
🟩 > 1 - 2
🟨 > 2 - 3
🟧 > 3 - 4
🟥 > 4

Road
Navigation Channel
River Mile Marker

Notes:
1. TOC data from FS dataset dated April 28, 2010.
2. Grid interpolated using the following parameters: Power 5, nearest neighbors 10/1, search radius 150x150 ft.

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Distribution of Total Organic Carbon in Surface Sediments

FIGURE 2-25

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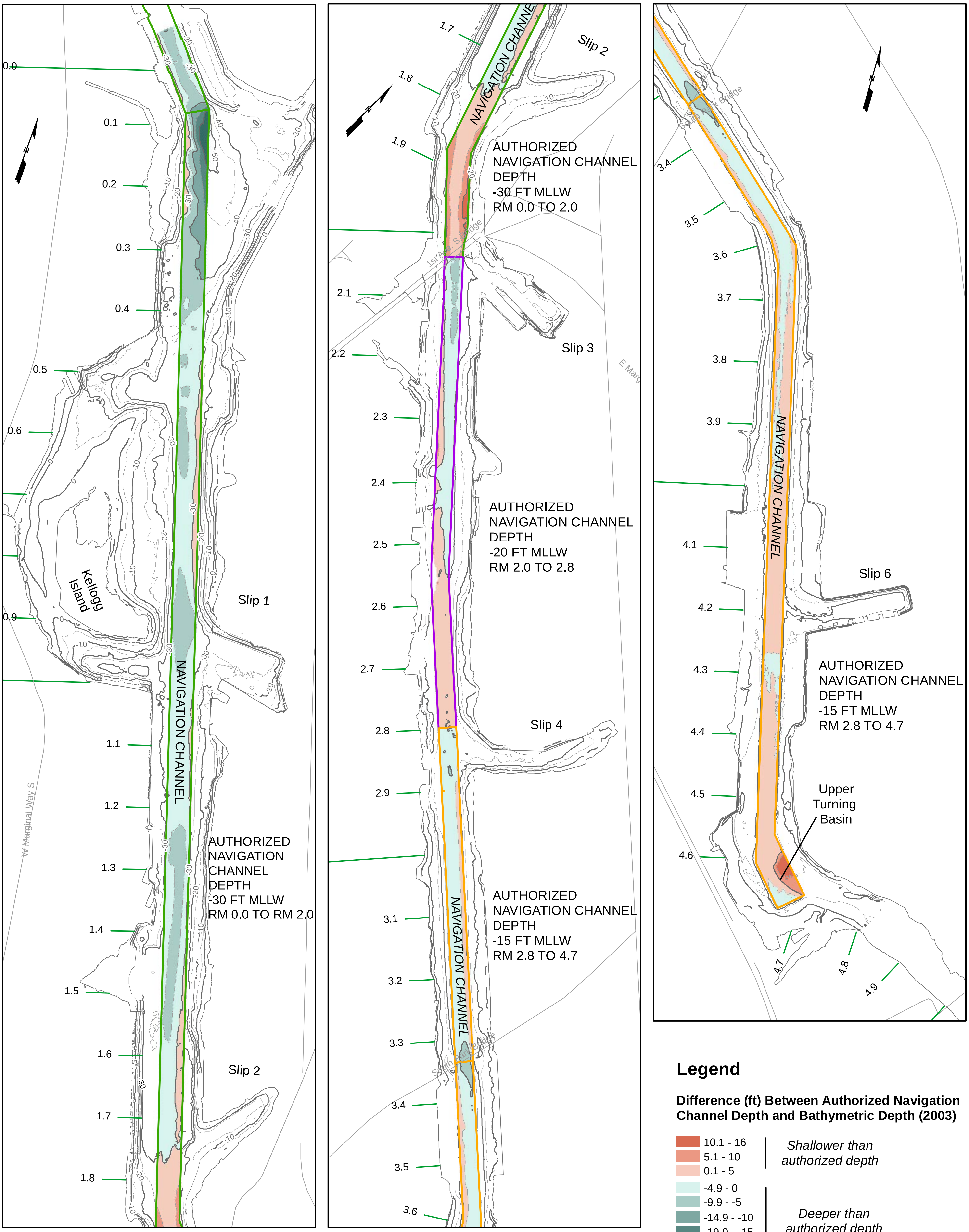

Notes:
1. Bathymetric data from David Evans and Associates October 2003 survey.
2. Navigation channel authorized depths and locations from NOAA chart 18450, Edition 18, Edition date 2/1/2004, Updated date 2/2/2008.

Legend

Difference (ft) Between Authorized Navigation Channel Depth and Bathymetric Depth (2003)

🟥 10.1 - 16
🟥 5.1 - 10
🟥 0.1 - 5
Shallower than authorized depth

🟩 -4.9 - 0
🟩 -9.9 - -5
🟩 -14.9 - -10
🟩 -19.9 - -15
🟩 -23.6 - -20
Deeper than authorized depth

☐ Outside of Authorized Navigation Channel

Authorized Navigation Channel Depth (ft MLLW)

☐ -30
☐ -20
☐ -15

— Road
— River Mile Marker
— Bathymetric Contour (ft MLLW)

0 200 400 800 Feet

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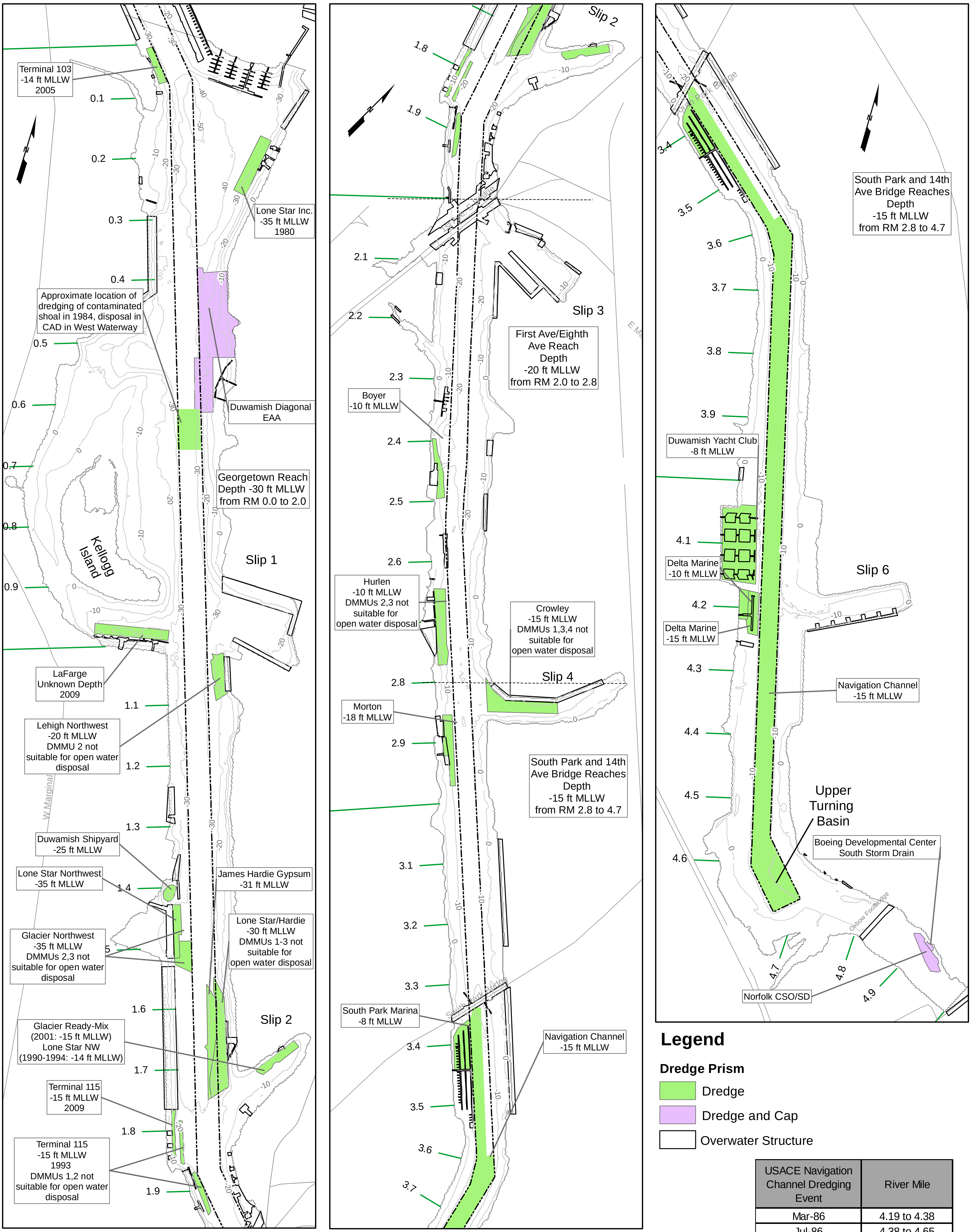
Revision: 0

2003 Bathymetric Conditions Relative to Authorized Navigation Channel Depths

FIGURE 2-26



Legend

Dredge Prism

🟩 Dredge

🟪 Dredge and Cap

☐ Overwater Structure

USACE Navigation Channel Dredging Event	River Mile
Mar-86	4.19 to 4.38
Jul-86	4.38 to 4.65
1987	4.38 to 4.65
1990	3.97 to 4.65
1992	3.34 to 4.65
1994	4.33 to 4.65
1996	4.02 to 4.48
1997	4.26 to 4.65
1999	3.43 to 4.65
2002	4.27 to 4.65
2004	4.33 to 4.65
2007	4.27 to 4.65
2010	4.05 to 4.65

Notes:
1. See Tables 2-9, 2-11, and 2-12 for additional information on dredging events and sources of information.
2. No authorized maintenance dredging depth for removal projects: Duwamish/Diagonal EAA, Norfolk CSO/SD, and Boeing Developmental Center South Storm Drain.
3. Overwater structures data created in 2004 by Terralogic GIS., Inc. and Landau Associates, Inc. and modified using 2007 high resolution oblique aerial photography and field investigations.
4. Approximate location of 1984 dredging from USACE Waterway Experiment Station, 1994. Material deposited in contained aquatic disposal (CAD) site in West Waterway.
5. DMMU= dredged material management unit.

Road

Navigation Channel

River Mile Marker

Bathymetric Contour (ft MLLW)

Extent of Navigation Channel Authorized Depth

Navigation Channel
-15 ft MLLW — Project Name

Authorized elevation (ft MLLW)

Feet
0 200 400 800

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Extent and Depth of Authorized Dredging Events (1980 to 2010)

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FIGURE 2-27

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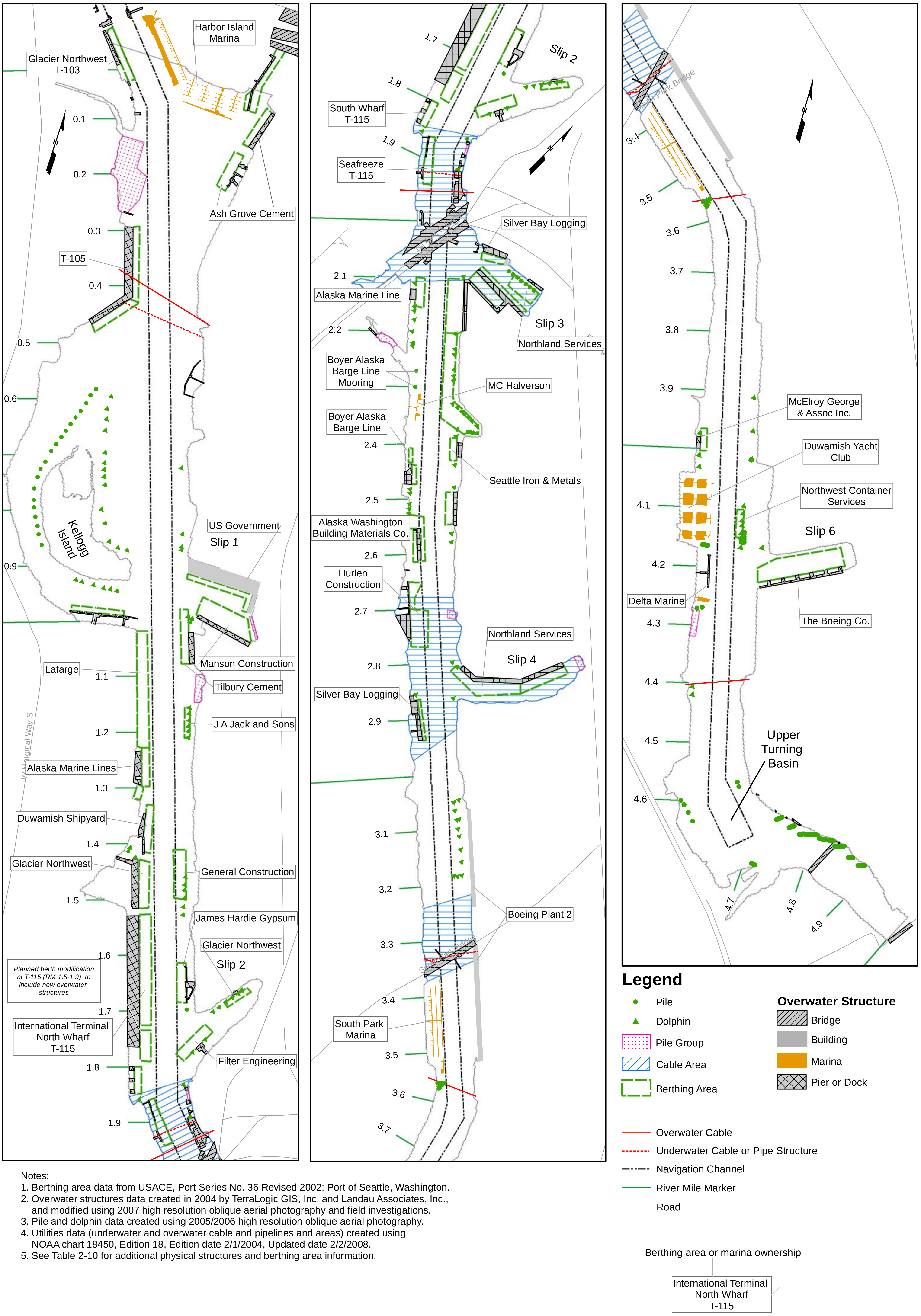

Notes:
1. Berthing area data from USACE, Port Series No. 36 Revised 2002; Port of Seattle, Washington.
2. Overwater structures data created in 2004 by TerraLogic GIS, Inc. and Landau Associates, Inc., and modified using 2007 high resolution oblique aerial photography and field investigations.
3. Pile and dolphin data created using 2005/2006 high resolution oblique aerial photography.
4. Utilities data (underwater and overwater cable and pipelines and areas) created using NOAA chart 18450, Edition 18, Edition date 2/1/2004, Updated date 2/2/2008.
5. See Table 2-10 for additional physical structures and berthing area information.

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In-water and Overwater Structures and Berthing Areas

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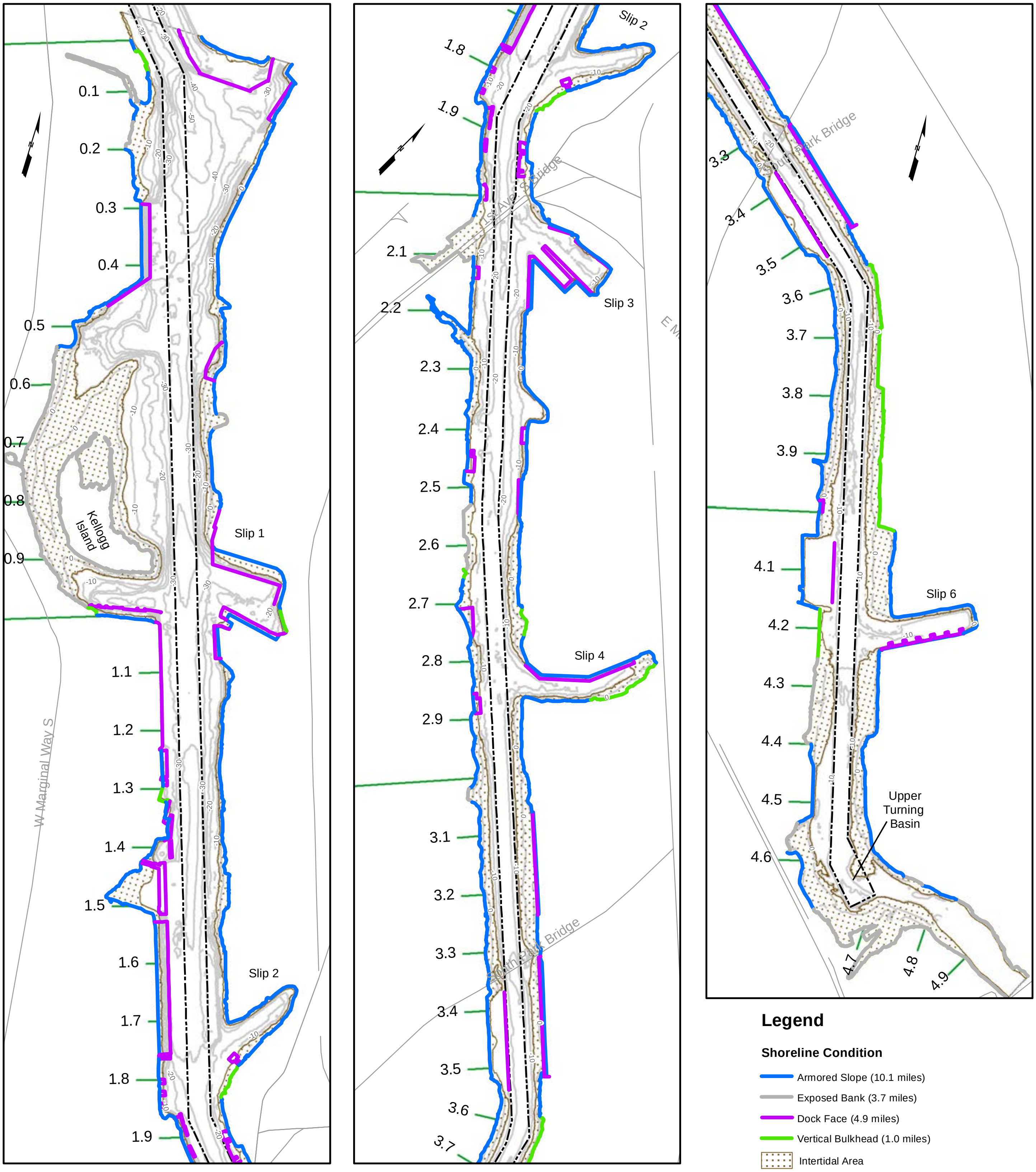
FIGURE 2-28



Legend

Shoreline Condition

- Armored Slope (10.1 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Vertical Bulkhead (1.0 miles)
- ▨ Intertidal Area
- Bathymetric Contour (ft MLLW)
- Road
- Navigation Channel
- River Mile Marker

Notes:
1. Shoreline conditions layer created using video from the 2005 Windward Environmental Human Access Survey, 2007 aerial imagery, and field investigation (2008 boat tour).
2. Mapped shoreline includes frontage of overwater structures, as well as riverbank.
3. Dock face refers to shoreline features including pile bents and a deck supporting some activity or structure. The overwater buildings at Boeing Plant 2 (RM 3.1-3.5) are mapped as dock face fronting an armored slope.

Feet
0 200 400 800

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Lower Duwamish Waterway Final Feasibility Study 60150279-14.34	**Shoreline Conditions**
DATE: 10/31/12 DWRN: MVI/sea Revision: 0	**FIGURE 2-29**

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3 Risk Assessment Summary

The baseline ecological and human health risk assessments were completed for the Lower Duwamish Waterway (LDW) in 2007 (Windward 2007a, 2007b). This section summarizes the findings of both risk assessments, which are used in Section 4 of this feasibility study (FS) to aid in establishing remedial action objectives (RAOs) and preliminary remediation goals (PRGs).

The baseline ecological risk assessment (ERA) (Windward 2007a) is discussed in Section 3.1, and presents the estimated risks for the benthic invertebrate community and for crabs, fish, and wildlife species. These receptors are exposed to contaminants in the LDW primarily through contact with sediment, water, or through consumption of prey species found in the LDW.

The baseline human health risk assessment (HHRA) (Windward 2007b) is discussed in Section 3.2, and presents the estimated risks for people who may be exposed to contaminants in the LDW through consumption of resident seafood from the LDW or through direct contact with sediment or water.

Both the baseline ERA and HHRA were based on the LDW Remedial Investigation (RI) baseline conditions.[1] For the early action areas (EAAs) where sediment cleanup occurred after December 2000 when the RI/FS Administrative Order on Consent (AOC) was issued (i.e., Duwamish/Diagonal and Boeing Developmental Center south storm drain), the pre-remedy data were used to characterize baseline conditions. However, sediment removal in the vicinity of the Norfolk combined sewer overflow/storm drain (CSO/SD) was conducted in 1999, so post-remedy monitoring data from the Norfolk CSO/SD area were used to represent baseline conditions in the RI.

The risk-based threshold concentrations (RBTCs), discussed in Section 3.3, represent calculated sediment and tissue concentrations estimated to be protective of a particular receptor for a given exposure pathway and target risk level. RBTCs were derived in the RI (Windward 2010) based on the baseline ERA and HHRA (Windward 2007a, 2007b). The RBTCs are also presented in this FS because they are used, along with other site information, to establish PRGs in Section 4. Finally, this section concludes with a summary of the key findings from the risk assessments (Section 3.4).

---

[1] Additional data have been collected since the finalization of the RI baseline dataset (i.e., since October 2006). The baseline dataset used in this FS (called the "FS baseline dataset") includes those data newer than October 2006, as well as older data that were not previously included (see Section 2, Table 2-2). In addition to the newer data, post-cleanup data in the perimeter of the Duwamish/Diagonal area were included in the FS baseline dataset. For the cap and enhanced natural recovery areas, only precleanup data were included in the FS baseline dataset. Additional details on the use of data from the Duwamish/Diagonal early action area in the FS are provided in Appendix N.

3.1 Baseline Ecological Risk Assessment

The baseline ERA (Windward 2007a) estimated risks for ecological receptors that may be exposed to contaminants in sediment, water, and through consumption of prey in the LDW.

Ten receptors of concern[2] were selected in the baseline ERA to be representative of groups of organisms in the LDW with the same exposure pathways. These receptors of concern include the benthic invertebrate community; crabs; juvenile Chinook salmon, Pacific staghorn sculpin, and English sole (collectively discussed as "fish"); and spotted sandpiper, great blue heron, osprey, river otter, and harbor seal (collectively discussed as "wildlife species").

A conservative risk-based screening process first identified contaminants of potential concern (COPCs) for the ERA (Windward 2007a). In this process, contaminant concentrations in sediment, water, and aquatic biota were compared to risk-based screening levels. Those contaminants present at concentrations above the screening levels or demonstrating the potential for unacceptable effects were identified as COPCs and underwent further risk analysis in the ERA.

Risks were estimated as follows:

- Risks for the benthic community were estimated by comparing contaminant concentrations in sediment with: 1) the numerical criteria of the Washington State Sediment Management Standards (SMS), 2) literature-derived toxicity reference values (TRVs), or 3) toxicologically based guidelines. Risks were also estimated based on site-specific sediment toxicity tests; a comparison of volatile organic compound (VOC) concentrations in porewater to toxicity data; a comparison of tributyltin (TBT) concentrations in benthic invertebrate tissues to concentrations associated with adverse effects; and a study of imposex in LDW-collected gastropods.
- Risks for crabs and fish were estimated by comparing contaminant concentrations in crab and fish tissue with tissue residues associated with effects on survival, growth, or reproduction.
- Risks for fish were also evaluated by comparing contaminant concentrations in prey to dietary concentrations that have been shown to cause adverse effects on survival, growth, or reproduction.
- For wildlife, risks were estimated based on calculations of daily doses of contaminants derived from the ingestion of sediment, water, and prey

---

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

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

The risks estimated for each of these receptors are summarized in the following sections.

3.1.1 Benthic Invertebrate Community

Contaminant concentrations in surface sediments were compared to the sediment quality standards (SQS) and the cleanup screening level (CSL) numerical chemical values of the SMS. For those that do not have SMS criteria, concentrations were compared with Dredged Material Management Program (DMMP) sediment quality guidelines (if they were toxicologically based) or with toxicity values from the scientific literature (i.e., TRVs). A contaminant was selected as a contaminant of concern (COC) if its concentration was found to be above the SQS criteria in one or more sediment samples from the LDW. Forty-four contaminants were identified as COCs for the benthic invertebrate community (Table 3-1). The three COCs with the most frequent exceedances were total polychlorinated biphenyls (PCBs), bis(2-ethylhexyl)phthalate (BEHP), and butyl benzyl phthalate. For all other COCs, exceedances occurred in 5% or less of the sediment samples.

When contaminant concentrations in surface sediment exceed the SMS criteria, the potential exists for harmful effects on the benthic invertebrate community living in intertidal and subtidal sediment. Based on the RI dataset, the SQS were exceeded in approximately 25% (110 acres) of the LDW study area. Of these 110 acres, a higher likelihood for adverse effects was identified in 31 acres, corresponding to approximately 7% of the LDW, where contaminant concentrations or biological effects resulted in exceedances of the CSL of the SMS. The other 79 acres (18% of the LDW) had contaminant concentrations or biological effects that exceeded the SQS but not the CSL. The remaining 75% of the LDW is considered unlikely to have adverse effects on the benthic invertebrate community based on the RI dataset.

Similar results were obtained using the FS dataset;[3] contaminant concentrations in approximately 18% (80 acres) of the LDW study area exceeded SMS criteria (i.e., exceedance of either the SQS and/or CSL). A higher likelihood of adverse effects was indicated in approximately 4% (16 acres) of the LDW study area because of CSL exceedances. The remaining 82% of the LDW was considered unlikely to have adverse effects on the benthic invertebrate community, based on the FS dataset.

Risks to the benthic invertebrate community from VOCs detected in sediment porewater were very low. One VOC, cis-1,2-dichloroethene, was detected in porewater samples collected from one small area located near Great Western International at river

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[3] See Section 2.2 of the FS for a discussion of the differences between the RI and FS datasets.

mile (RM) 2.4E. The concentrations for this VOC were greater than the no-observed-effect concentration (NOEC) for the marine invertebrates but were less than the lowest-observed-effect concentration (LOEC). Because this location is considered to be a worst-case exposure area with respect to the potential for adverse effects to benthic invertebrates from VOCs, and other areas where porewater data are available had much lower VOC concentrations, the likelihood of risks from VOCs is very low in the rest of the LDW.

Finally, risks to benthic invertebrates from TBT, which has no SQS criterion, were considered to be low. This finding was based on a study of imposex in LDW-collected gastropods, as well as a comparison of TBT concentrations in benthic invertebrate tissue samples to tissue effect concentrations from the scientific literature.

3.1.2 Crabs, Fish, and Wildlife Species

Risks for crabs exposed to COPCs were estimated by comparing COPC concentrations in LDW crab tissue to effects data obtained from the scientific literature, including no-observed-adverse-effect levels (NOAELs) and lowest-observed-adverse-effect levels (LOAELs). Risks were estimated by calculating hazard quotients (HQs) as the ratio of the COPC concentrations in LDW crab tissue to the selected NOAELs and LOAELs for crab tissue.

For fish receptors of concern, HQs were calculated using both a critical tissue-residue approach and estimated dietary exposures, as well as a range of effects data obtained from the scientific literature, including NOAELs and LOAELs.

For wildlife receptors of concern, HQs were calculated for estimated dietary exposures and were based on a range of effects data obtained from the scientific literature, including NOAELs and LOAELs.

COCs for crabs, fish, and wildlife species were defined as contaminants with LOAEL-based HQs greater than or equal to 1, which indicate a potential for adverse effects. One contaminant (total PCBs) was identified as a COC for crabs. Total PCB concentrations in crab tissue were equal to the lowest concentrations associated with adverse effects in crabs, indicating potential for adverse effects. Seven contaminants (total PCBs, cadmium, chromium, copper, lead, mercury, and vanadium) were identified as COCs for at least one fish or wildlife species (Table 3-2).

No quantitative risk estimates were calculated for dioxins/furans in the RI because tissue data were not available from the LDW. Therefore, risks to ecological receptors associated with tissue burdens or dietary exposure to dioxins/furans are unknown.

3.1.3 Risk Drivers for Ecological Receptors

A subset of the COCs was identified as risk drivers for ecological receptors in accordance with guidance from the U.S. Environmental Protection Agency (EPA 1998a) and the Washington State Department of Ecology (Ecology) (WAC 173-340-703). A detailed explanation of the rationale for identifying these risk drivers can be found in Section 7 of the baseline ERA (Windward 2007a) and is summarized in Tables 3-1 and 3-2. Risk drivers for ecological receptors of concern were selected by considering: 1) the uncertainty in risk estimates based on quantity and quality of exposure and effects data, 2) natural background concentrations, and 3) the likely magnitude of residual risks following planned sediment remediation in EAAs.

In the baseline ERA (Windward 2007a), 44 contaminants were selected as COCs for benthic invertebrates. Of these, 41 contaminants were selected as risk drivers for benthic invertebrates because they had concentrations greater than the SQS in at least one sediment sample (Table 3-1). The other three contaminants (nickel, dichlorodiphenyl-trichloroethanes (DDTs), and chlordane) were identified as COCs based on concentrations greater than TRVs or toxicologically based DMMP guidelines; these three contaminants were not selected as risk drivers because of uncertainties in effects data and because sediment samples with concentrations greater than the TRVs or guidelines were all (except for one) located within EAAs (Windward 2007a). In consultation with EPA and Ecology, total PCBs were identified as a risk driver for river otter because estimated dietary exposure concentrations for river otter were greater than the LOAEL by a factor of 2.9 and uncertainties in the risk estimate were relatively low (Table 3-2). Although no other COCs were identified as risk drivers for fish or wildlife species, the other COCs were evaluated to assess the potential for risk reduction following remedial actions and the results of this analysis are presented in Section 9 of this FS.

3.2 Baseline Human Health Risk Assessment

The baseline HHRA (Windward 2007b) estimated risks to people from exposure to contaminants in LDW seafood, sediments, and water. The exposures were assumed to occur through consumption of resident seafood harvested from the LDW, and through direct contact with sediments during netfishing, clamming, or beach play (the exposure pathways). Risks associated with direct contact with water (i.e., swimming) are much lower than those estimated for direct sediment contact (Windward 2007b), and are therefore not discussed further in the FS.

Direct-contact risk estimates in the HHRA (Windward 2007b) for the beach play and clamming scenarios were based on the uppermost 10 cm of sediment in the beach play and clamming areas because most of the surface sediment data collected in the LDW was collected to a depth of 10 cm. However, children and clammers may dig holes deeper than 10 cm. The most abundant clam species of harvestable size in the LDW is the Eastern soft-shell clam (*Mya arenaria*), which has been reported to burrow to depths that range from 10 cm to 20 cm based on two Pacific Northwest species guidebooks (Kozloff 1973, Harbo 2001) and from 10 to 30 cm based on studies conducted throughout the United States (e.g., Blundon and Kennedy 1982, Cohen 2005, Hansen et al. 1996, Evergreen State College 1998). To ensure protection of human health, a sediment depth of 45 cm is used as the point of compliance depth in this FS for clamming and beach play areas in the LDW. This depth accounts for the potential exposure of children and clammers who may come into direct contact with sediment when digging holes in the sediment at low tide.

Using EPA guidance, a risk-based screening was first performed to identify the COPCs to be evaluated. This screening was based on an exceedance of the screening criteria (i.e., the risk-based concentration) by either the maximum detected concentrations or analytical reporting limits (RLs) (for samples with non-detected concentrations). The risk-based screening identified the following COPCs by exposure pathway: 59 COPCs for seafood consumption pathways, 20 COPCs for netfishing, and 28 COPCs for beach play and clamming direct contact pathways. COPCs that were not detected in either sediment or tissue were still included if they had RLs above the screening criteria; however, those COPCs were evaluated only in the uncertainty analysis.

For the detailed risk analysis of the COPCs, reasonable maximum exposure (RME) estimates were calculated for the exposure pathways evaluated in the HHRA (Windward 2007b) to avoid underestimating risks. The RME is the highest exposure that is reasonably expected to occur at a site. The RME, by definition, likely overestimates exposure for many individuals.

Risks estimated for the seafood consumption and direct exposure scenarios evaluated in the HHRA (Windward 2007b) are discussed in the following subsections.

3.2.1 Risks Associated with the Seafood Consumption Pathway

No seafood consumption surveys specific to the LDW were available for use in the HHRA (Windward 2007b). Therefore, seafood consumption rates assumed for the LDW were developed by EPA based on data collected from other areas of Puget Sound for tribal consumers and from an EPA consumption study for Asian and Pacific Islanders (API) in the King County area.

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

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

The tribal consumption rates of resident seafood are likely overestimates of current consumption. However, such rates may be achieved in the LDW at some future time. The rates used are generally similar to those for other populations who consume large quantities of seafood in the absence of seafood consumption health warnings.

Other seafood consumption scenarios were also evaluated in the baseline HHRA (Windward 2007b). These other scenarios included consumption rates estimated using: 1) Suquamish tribal consumption rates from EPA's tribal framework document (EPA 2007b), 2) "average exposure" scenarios using central tendency consumption rate estimates, and 3) a "unit risk" scenario based on an assumed one seafood meal per month. Estimates for the unit risk scenario are useful for risk communication because individuals can determine what their risk might be for various seafood consumption practices.

It is noted that there is considerable uncertainty about the applicability of seafood consumption rates in the baseline HHRA (Windward 2007b), particularly for clams, given the quality and quantity of shellfish habitat in the LDW. Nonetheless, their use in the HHRA reflects health-protective estimates of risk.

Contaminant concentrations in the tissues of several different resident seafood species (e.g., English sole, perch, crabs, clams, mussels) were used to represent a typical consumer's diet. COCs were then determined by estimating cancer and non-cancer effects for the RME scenarios. Contaminants with an estimated excess cancer risk greater than 1 in 1,000,000 (1×10^{-6}) or a non-cancer HQ greater than 1 were selected as COCs for the seafood consumption exposure pathway. Nineteen contaminants were identified as COCs for the seafood consumption exposure pathway (Table 3-3).[4]

The total risk for all carcinogenic contaminants for the various RME seafood consumption scenarios ranged from 7 in 10,000 (7×10^{-4}) to 4 in 1,000 (4×10^{-3}),[5] with the primary contributors to risk being total PCBs, arsenic, and carcinogenic polycyclic

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[4] As noted in Table 3-3, both total PCBs and PCB toxic equivalent (TEQ) were identified in the HHRA as COCs. Because these two COCs represent different methods of evaluating the same contaminant, they are counted as one COC in the count presented here.

[5] The highest RME total excess cancer risk estimate reported here (4×10^{-3}) differs from that reported in Appendix B of the RI (the HHRA, Windward 2007b) and Section 6 of the RI (3×10^{-3}) (Windward 2010). The apportionment of shellfish (i.e., the amount of crab consumed relative to other shellfish) for scenarios based on the Tulalip Tribes survey was updated in response to a correction provided by EPA. The influence of this correction on the total risk estimates is relatively minor. This change and its impact on risk estimates are described in detail in an erratum (Windward 2009) to Appendix B of the RI (Windward 2010). This total risk estimate includes risks from total PCBs but excludes risks from PCBs from a TEQ perspective to avoid double counting dioxin-like PCB risks posed by coplanar PCB congeners that are already accounted for in the slope factor for PCBs.

aromatic hydrocarbons (cPAHs) (Table 3-4a).[6] In addition, evaluation of non-cancer HQs indicates the potential for adverse effects other than cancer associated with seafood consumption, particularly from total PCBs (Table 3-4b).

To provide additional information regarding the total excess cancer risks for the RME seafood consumption scenarios, Table 3-5 presents a summary of the excess cancer risks for COCs and includes the percentages of the total risks attributable to different COCs and seafood consumption categories (i.e., fish, crabs, and clams). The main contributors to the total excess cancer risk for the RME seafood consumption scenarios were arsenic (40 to 50% of the total risk) and total PCBs (38 to 43% of the total risk). In addition, Table 3-5 shows that the majority of the arsenic and cPAH risks (96 to 98%) are attributable to clams, while the total PCB risk is attributable to several different seafood consumption categories (primarily clams [39 to 47%], pelagic fish [23 to 25%], and whole-body crabs [15%]).

It is important to recall that the risk estimates presented in the baseline HHRA (Windward 2007b) did not include the risks associated with dioxins/furans in seafood tissues because no tissue data for dioxins/furans were available at that time from the LDW. More recently, a small dataset became available for dioxin/furan concentrations in English sole fillets collected near Kellogg Island in 2007 as part of the Puget Sound Ambient Monitoring Program (Gries 2008). It should be noted that these data were collected from only a small portion of the LDW that has relatively low concentrations of dioxins/furans in sediments. These data were not included in formal risk calculations because there are no dioxin/furan tissue data from the LDW for the other seafood categories.

However, in an attempt to put these new dioxin/furan concentration data in context, excess cancer risks were calculated assuming all seafood categories had the same dioxin/furan concentrations as the English sole fillet samples collected near Kellogg Island. Based on this assumption, the excess cancer risks associated with dioxins/furans would be an order of magnitude or more lower than the total excess cancer risks (all other contaminants combined) for all three RME seafood consumption scenarios and therefore inclusion of dioxin/furan tissue data may not have substantially changed the overall risks (Table 3-5). However, COC concentrations can vary substantially across organism, tissue type, and location. Conclusive statements about the contribution of dioxins/furans to overall risk would require collection of additional dioxin/furan data for all of the organisms and tissue types considered in the HHRA. In addition, the tissue data would have to be spatially representative, not just from limited areas of the LDW (e.g., Kellogg Island).

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[6] Seafood samples from the LDW were not analyzed for dioxins and furans, so risks from these contaminants are not included in seafood consumption risk estimates, but were assumed to be unacceptable.

3.2.2 Risks Associated with Direct Sediment Contact

No LDW-specific data are available for estimating the degree to which humans may currently be directly exposed to sediment via beach play or clamming. To ensure protection of human health, RME values for the beach play and clamming scenarios were identified based on regional data and best professional judgment. These values likely overestimate current exposure but provide information to risk managers for evaluating potential increases in site use following remediation. The tribal netfishing scenario, on the other hand, reflects exposure conditions that could occur under current tribal fishing practices within the LDW. Netfishing can occur throughout the LDW, while clamming and beach play would occur in specific areas of the LDW. The potential clamming areas and beach play areas are shown on Figure 3-1.

Contaminants with either an estimated excess cancer risk greater than 1 in 1,000,000 (1×10^{-6}) or a non-cancer HQ greater than 1 for at least one RME scenario were selected as COCs for the direct sediment contact exposure pathways. Five contaminants were identified as COCs for direct sediment contact exposure (Table 3-3). The primary contributors to risk included total PCBs, arsenic, cPAHs, and dioxins/furans;[7] toxaphene was also identified as a COC, but it was only a tentatively identified compound and therefore its contribution to risk is highly uncertain.

3.2.2.1 Netfishing and Clamming Scenarios

As presented in the RI (Windward 2010), total excess cancer risk estimates for the direct sediment contact RME scenarios were 3 in 100,000 (3×10^{-5}) for netfishing and 1 in 10,000 (1×10^{-4}) for tribal clamming (Table 3-6a); neither of these direct sediment contact exposure scenarios had non-cancer HQs greater than 1. Dioxins/furans were a significant contributor to total carcinogenic risk for the netfishing and tribal clamming scenarios in the HHRA (2×10^{-5} [vs. a total risk of 3×10^{-5}] and 1×10^{-4} [equal to the total risk of 1×10^{-4}], respectively). The dataset for dioxins/furans available for the HHRA was much smaller than the FS dataset (see Section 2.2.1),[8] and the exposure point concentrations for dioxins/furans for these scenarios in the HHRA were highly influenced by a few high data points. When total excess cancer risks were recalculated using the much larger FS dataset, the dioxin/furan risk associated with netfishing was 3×10^{-6}, and the dioxin/furan risk associated with clamming was 5×10^{-5}.

Since the HHRA (Windward 2007b) was finalized, additional sediment samples have been collected and are now included as part of the FS dataset. If this FS dataset were used to recalculate netfishing and clamming risk estimates for the other risk drivers

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[7] Dioxins/furans were analyzed in sediments, and therefore, direct contact risk estimates are available.

[8] There were 43 sediment samples available to characterize dioxin/furan TEQ netfishing exposure in the HHRA dataset, compared to 189 sediment samples in the FS dataset. There were 11 sediment samples available to characterize dioxin/furan TEQ tribal clamming exposure in the HHRA dataset, compared to 37 sediment samples in the FS dataset.

(i.e., total PCBs, arsenic, and cPAHs), risks would be similar to or lower than those calculated in the HHRA (Windward 2007b) for arsenic and cPAHs. However, for total PCBs, risk estimates would be higher based on the inclusion of two samples with very high PCB concentrations (2,900,000 micrograms per kilogram dry weight [µg/kg dw] and 230,000 µg/kg dw) collected in May 2007 from the head of the inlet at RM 2.2W. If these two samples were excluded, the risk estimates would be slightly lower than those calculated in the HHRA.

3.2.2.2 Beach Play Scenarios

As presented in the RI (Windward 2010), total excess cancer risk estimates ranged from 5 in 1,000,000 (5×10^{-6}) to 5 in 100,000 (5×10^{-5}) for the eight individual beach play areas evaluated as part of the beach play RME exposure scenario (Table 3-6a). Non-cancer HQs were less than 1 for all of the eight beach play areas.

Since the HHRA was finalized (Windward 2007b), additional sediment samples have been collected in many of the beach play areas; the data from the analysis of those samples have been incorporated into the FS dataset (see Section 2.2). This dataset was used to update beach play risk estimates for the individual beach play areas. Details regarding how the updated risk estimates were calculated, including specific information about the calculation of exposure point concentrations, are presented in Appendix B.

Based on the FS dataset, the estimated total excess cancer risks (for all four human health risk drivers combined) ranged from 2 in 1,000,000 (2×10^{-6}) to 6 in 10,000 (6×10^{-4}) for the individual beach play areas (Table 3-6b and Figure 3-1). The estimated total excess cancer risks for beach play were lower for Areas 1, 3, 7, and 8 based on the FS dataset (Table 3-6b) compared with the estimated total excess cancer risks for those areas based on the HHRA dataset (Table 3-6a) (Windward 2007b). The other beach play areas (Areas 2, 4, 5, and 6) had higher risk estimates based on the FS dataset, with Area 4 having the greatest increase in the estimated risk. This increase was largely the result of high PCB concentrations in two post-RI samples that were collected from the head of the inlet at RM 2.2W (i.e., 2,900,000 µg/kg dw and 230,000 µg/kg dw).

To provide additional information for risk communication, excess cancer risks were estimated separately for Duwamish Waterway Park (which is part of Area 5 [Figure 3-1]). In addition, excess cancer risks for Areas 4 and 5 were also estimated based on data for subsets of each of these areas. Area 4 was divided into two parts. The first part included all sediment samples except those in the inlet at RM 2.2W (referred to as Area 4 modified – without inlet). The other part included only those samples in the inlet at RM 2.2W (referred to as Area 4 modified – inlet only). Area 5 was divided into two parts. The first part (referred to as Area 5 modified – south) included the two southernmost sections of Area 5. The other part (referred to as Area 5 modified – north) included only the northernmost section of Area 5. These modified areas were assessed to facilitate remedial decision-making (i.e., clarify which portions of these beach play areas are causing most of the risk).

The estimated excess cancer risks for Duwamish Waterway Park were presented in Section 6 of the HHRA (Windward 2007b). The total excess cancer risk for arsenic, cPAHs, and total PCBs was 4 × 10^{-6}. No dioxin/furan data were available for Duwamish Waterway Park when the HHRA was completed. The updated total excess cancer risk estimate for Duwamish Waterway Park using the FS dataset for arsenic, cPAHs, total PCBs, and dioxins/furans was 2 × 10^{-6}.

The estimated total excess cancer risk for Area 4 modified – without inlet (1 × 10^{-5}) was much lower than that for either Area 4 modified – inlet only (3 × 10^{-3}) or for the entire Area 4 (6 × 10^{-4}) (Table 3-6b). This result is consistent with the higher concentrations of arsenic, dioxins/furans, cPAHs, and especially total PCBs found within the inlet. The estimated total excess cancer risk for Area 5 modified - south (4 × 10^{-6}) was also much lower than that for either Area 5 modified – north (5 × 10^{-5}) or for the entire Area 5 (3 × 10^{-5}) (Table 3-6b, Figure 3-1). This result was also consistent with the higher concentrations of cPAHs and dioxins/furans found in the northernmost portion of Area 5.

In addition to the increased excess cancer risk estimates for some beach play areas (as presented in Table 3-6b), the highest non-cancer HQ (Area 4) for total PCBs increased from 1 (as presented in the HHRA [Windward 2007b]) to 187 based on the newer (i.e., post-RI) data (Appendix B, Table B-2). The increase in the HQ is largely a result of the two samples with very high total PCB concentrations from the head of the inlet at RM 2.2W. If those two high total PCB concentrations were omitted, the non-cancer HQ for total PCBs for Area 4 would be 2 (similarly, the excess cancer risk would decrease from 6 × 10^{-4} to 6 × 10^{-6} if these two samples were excluded). The non-cancer HQ for total PCBs for Area 4 modified – without inlet is 0.4. This analysis suggests that the area of most concern is the inlet at Area 4 (which has been prioritized for remedial action in Alternative 2; see Section 8, Figure 8-6). None of the other beach play areas had non-cancer HQs greater than 1 for any contaminant.

3.2.3 Sum of Risks Across Multiple Exposure Scenarios

Risks for multiple exposure scenarios can be summed to represent possible exposure of the same individuals to LDW contaminants during different activities. Summed risks (i.e., the sum of risks across pathways) are presented in Table 3-7 for the following multiple exposure scenarios:

- Adult Tribal RME netfishing, Adult Tribal RME seafood consumption, and swimming
- Child Tribal RME seafood consumption, beach play RME, and swimming

- Adult Tribal RME clamming, Adult Tribal RME seafood consumption, and swimming.[9]

When estimated excess cancer risks were rounded to one significant figure, the sums for two of the three scenario groups above were the same as the estimates for the seafood (or clam) consumption alone. Summing risks for the Child Beach Play RME and swimming scenarios with the Child Tribal RME seafood consumption increased the estimated risks only slightly over those for seafood consumption alone. Overall, swimming had the lowest risk estimates.

This analysis demonstrates that the contributions to the sum of risks from netfishing, clamming, beach play, and swimming are relatively small in comparison to estimated risks from seafood consumption alone. This finding highlights the significance of the seafood consumption exposure pathway for all users of the LDW. Despite the lower magnitude of direct contact risks versus seafood consumption risks, several direct contact exposure risk estimates were close to the upper end of EPA's acceptable risk range of 1 in 10,000.

3.2.4 Risk Drivers for Human Health

Four COCs were selected as risk drivers for both the seafood consumption and direct sediment exposure scenarios: total PCBs, arsenic, cPAHs, and dioxins/furans.[10] A detailed explanation of the rationale for identifying these risk drivers can be found in Section 7 of the baseline HHRA (Windward 2007b) and is summarized in Table 3-8. Briefly, the risk drivers were selected based on the magnitude of their risk estimates and the relative percentage of their contributions to the total human health risk. Other factors considered in their selection were toxicological characteristics, persistence in the environment, natural background concentrations, and detection frequency. COCs not selected as risk drivers in the baseline HHRA are evaluated in Section 9.11 to assess the potential for risk reduction following remedial actions.

3.3 Risk-based Threshold Concentrations

For the LDW, RBTCs are concentrations of risk-driver COCs in sediment or tissue that are associated with specific risk estimates and exposure pathways. Cleanup of sediment to concentrations at or below a specific RBTC is predicted to be protective for the particular risk drivers, based on the exposure assumptions of the baseline risk assessments (Windward 2007a, 2007b). RBTCs for tissue and sediment were presented

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[9] Although some individuals might engage in both netfishing and clamming, risks for these two scenarios were not summed, because engaging in both at the frequency assumed for each (more than 100 days per year) is unlikely.

[10] Dioxins/furans were identified as a risk driver for human seafood consumption, even though no quantitative risk estimates were made.

in Section 8 of the RI (Windward 2010), and were used in this FS along with other site information to establish PRGs (as presented in Section 4).

3.3.1 Sediment RBTCs

Risk drivers for ecological receptors include the SMS contaminants with concentrations that exceeded the SQS in one or more surface sediment samples, as well as total PCBs for river otter; the risk drivers for human health include total PCBs, arsenic, cPAHs, and dioxins/furans. Sediment RBTCs for the ecological risk drivers include the following:

- The SQS and CSL sediment criteria from the SMS for the protection of benthic invertebrates (see Table 3-1 for these SMS values).
- Total PCB concentrations in sediment necessary to achieve sufficiently low total PCB concentrations in tissue for the protection of seafood consumption by river otters (128 to 159 µg/kg dw, depending on the diet assumptions for the river otter that were used in the ERA) (Table 3-9).

Sediment RBTCs for the human health risk drivers were calculated at three different excess cancer risk levels and for HQs equal to 1 (when the non-cancer hazard was greater than 1 in the HHRA) for both the direct contact with sediment scenarios (i.e., beach play, netfishing, and tribal clamming) and the seafood consumption scenarios. The equations used to calculate the sediment RBTCs are based on the risk equations used in the baseline HHRA (Windward 2007b).

Sediment RBTCs for the human health direct sediment contact exposure scenarios were calculated for all four risk drivers (i.e., PCBs, arsenic, cPAHs, and dioxins/furans) at all three excess cancer risk levels (Table 3-10). With one exception, sediment RBTCs were not calculated for non-cancer hazards (at an HQ of 1) because all HQs were less than or equal to 1 for the RME scenarios in the HHRA (Windward 2007b). The one exception was for the beach play RME scenario, for which the HQ calculated for total PCBs using the FS dataset for Area 4 was greater than 1.0 (see Section 3.2.2.2 for details).

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

- **Total PCB sediment RBTCs:** A food web model calibrated for the LDW (see Appendix D of the RI) was used to estimate the relationship between sediment and tissue concentrations for total PCBs, and to calculate sediment RBTCs. For the 1 in 10,000 (1×10^{-4}) excess cancer risk level, the food web model-calculated sediment RBTCs ranged from 7.3 to 185 µg/kg for the three RME scenarios (Table 3-9). For the excess cancer risk levels of 1 in 1,000,000 (1×10^{-6}) (required by MTCA) and 1 in 100,000 (1×10^{-5}) and for the non-cancer HQ of 1, total PCB sediment RBTCs were estimated to be less than 1 µg/kg dw (Table 3-9). Sediment RBTCs for these lower risk levels are especially difficult to quantify for several reasons. First, the food web model was calibrated for baseline conditions (i.e., a sediment concentration of 380 µg/kg PCBs), not post-remedy conditions. The greater the difference between baseline and post-remedy conditions, the greater the uncertainty in the model application. Second, at these very low sediment total PCB concentrations, the assumed total PCB concentration in water becomes increasingly important and is also uncertain. Because contaminant concentrations in both sediment and water contribute to tissue concentrations in aquatic organisms, even if total PCB sediment concentrations were assumed to be 0 µg/kg dw, water total PCB concentrations would need to be well below upstream Green River total PCB concentrations (which are currently 0.3 nanograms per liter [ng/L] on average) to calculate concentrations in tissue that would equate to these lower risk levels (see Section 3.3.2 for tissue RBTC discussion). While sediment contaminant concentrations can be directly addressed through source control and sediment remediation, surface water contaminant concentrations can only be indirectly addressed. The indirect methods make it difficult to estimate the extent to which surface water contaminant concentrations may be reduced. Only at substantially lower hypothetical water contaminant concentrations that are very probably unachievable for the LDW would the sediment RBTCs for the 1×10^{-5} or the 1×10^{-6} risk level be greater than 0 µg/kg dw (Figure 3-2). For example, using a hypothetical water concentration of 0.01 ng/L, the sediment RBTC would be greater than 0 µg/kg dw for the 1×10^{-5} risk level (equal to approximately 3.9 µg/kg dw, as shown in Figure 3-2).

- **Dioxin/furan sediment RBTCs:** The HHRA (Windward 2007b) was conducted with the assumption that risks associated with exposure to dioxins and furans through seafood consumption were unacceptable, and that the RTBCs for those risks would be more stringent than natural background concentrations. As a result, tissue data were not collected and analyzed to calculate specific exposure estimates, except for a limited data set collected from a small area of the LDW,[11] discussed in Section 3.2.1. Consequently, sediment RBTCs for dioxins/furans for seafood ingestion scenarios could not be, and were not, calculated. Because the RBTCs were assumed to be more stringent than natural background values, natural background values are used as sediment PRGs for dioxins/furans, as required by MTCA, to address seafood consumption in this FS in lieu of RBTCs (see Section 4).

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[11] A total of six composite English sole fillets were collected in May 2007 near Kellogg Island and analyzed for dioxins/furans. Data for other seafood categories were not collected.

- **Arsenic and cPAH sediment RBTCs:** For arsenic and cPAHs, 95% or more of the risk associated with seafood consumption for the RME scenarios is attributable to the consumption of clams. Therefore, a relationship between arsenic and cPAHs concentrations in clams and sediment is required to estimate sediment RBTCs. However, despite efforts to better understand these relationships, EPA and Ecology agree with the Lower Duwamish Waterway Group that the clam tissue-to-sediment relationships based on the RI data for both arsenic and cPAHs were too uncertain to develop quantitative sediment RBTCs (see Sections 8.3.2 and 8.3.3 in the RI [Windward 2010]). For example, in some areas with elevated arsenic sediment concentrations, a corresponding elevation in clam tissue was not found, and other areas with comparatively low levels of arsenic in sediments contained clams with elevated arsenic tissue concentrations. Further research will be conducted prior to sediment remediation to better understand and characterize the relationship between sediment and tissue arsenic and cPAH concentrations. The results will inform remedial actions in clam habitat areas. The efficacy of completed remedial actions in reducing cPAH and arsenic concentrations in clams will be evaluated through monitoring. Further remedial actions may be required to reduce levels of cPAHs and arsenic in aquatic biota if initial efforts are unsuccessful.

3.3.2 Tissue RBTCs

Tissue RBTCs associated with the three RME seafood consumption scenarios were calculated for all four risk drivers (i.e., total PCBs, inorganic arsenic, cPAHs, and dioxins/furans) for excess cancer risk thresholds and for total PCBs and inorganic arsenic for a non-cancer HQ of 1 (Table 3-11). The risk equations and parameters used to calculate the tissue RBTCs are the same as those used in the RI, and are presented in Table 3-12. To derive the tissue RBTCs, these equations were solved for the concentration in seafood for a given target risk level using scenario-specific parameters (e.g., ingestion rates, body weights).

The tissue RBTCs for the seafood consumption scenarios presented in Table 3-11 represent the ingestion-weighted average concentrations in tissue that correspond to a certain risk threshold for each scenario. For example, the RBTC for total PCBs for the Adult Tribal RME seafood consumption scenario based on Tulalip data was 4.2 µg/kg ww at the 1×10^{-5} excess cancer risk level. Thus, the consumption of 97.5 g/day (the daily ingestion rate for the Adult Tribal RME scenario based on Tulalip data) of any tissue type with a total PCB concentration of 4.2 µg/kg ww for 70 years would result in a 1×10^{-5} excess cancer risk. The consumption of numerous types of seafood, such as crabs, clams, and fish (as specified in the exposure parameters for the Adult Tribal RME scenario based on Tulalip data), would also result in a 1×10^{-5} excess cancer risk as long as the ingestion-weighted average of the various tissue concentrations was 4.2 µg/kg ww. As shown in Table 3-11, the tissue RBTCs for the Adult Tribal RME scenario based on Tulalip data were lower than those for the other RME scenarios for a given risk threshold for each risk driver.

Species-specific tissue RBTCs for diets with a mixture of seafood (such as those for the RME scenarios evaluated in the HHRA) can also be calculated. These RBTCs are useful for comparison with single-species data collected during long-term monitoring programs to assess improvements in residual risks following cleanup actions. To calculate these RBTCs, two assumptions are required: 1) the diets in the RME scenarios remain the same over time, and 2) the relative concentrations in various seafood types consumed co-vary (i.e., decrease by a proportional amount) in the future. Changes in either of these assumptions would result in changes to species-specific tissue RBTCs. Uncertainty in RBTCs is associated with the use of these assumptions. Variability exists in the PCB concentration relationships between different organism/tissue types based on the different sources of PCB organism/tissue type data used to characterize these relationships. Data sources that were evaluated included: 1) PCB data used for the HHRA; 2) the food web model used to characterize PCB bioaccumulation; and 3) PCB data collected in 2007. It should be noted that the dataset used for the HHRA had more samples than the 2007 dataset because it represented a combination of many years of data.[12] The equations and methods used to calculate these RBTCs and the resulting species-specific tissue RBTC concentration ranges for PCBs are presented in Section B.3 of Appendix B.

Species-specific tissue RBTCs are presented in Tables 3-13 through 3-15 for the three RME seafood consumption scenarios. For informational purposes, LDW tissue data and tissue data from non-urban locations in Puget Sound are also presented.[13] Additional details regarding the Puget Sound dataset are provided in Appendix B, Section B.4. In addition, Figures 3-3 through 3-6 present the ingestion-weighted average RBTCs along with calculated ingestion-weighted average tissue concentrations based on the non-urban Puget Sound tissue dataset and on available LDW tissue data. These figures present ingestion-weighted tissue concentrations for the LDW and Puget Sound tissue datasets because these are more directly comparable to the RBTCs (which are based on market basket consumption). These ingestion-weighted concentrations were calculated by multiplying the tissue concentration for each consumption category by its percent of the total consumption rate, and then summing the results.

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[12] The dataset used to evaluate risks in the HHRA contained 221 total PCB tissue samples from throughout the LDW between 1992 and 2005. The 2007 dataset contains a total of 86 tissue samples (including benthic fish, pelagic fish, clam, and crab samples), which were intended to characterize tissue concentrations further in the LDW.

[13] Tables 3-13 through 3-15 present the LDW tissue data used to calculate risks in the HHRA (which includes samples collected between 1992 and 2005). Additional tissue samples collected from the LDW in 2007 are not shown in these tables, but can be found in the RI (Sections 4 and 8).

3.4 Key Findings of the Baseline Risk Assessments

Key findings for the baseline ERA (Windward 2007a) and HHRA (Windward 2007b) are as follows:

- Forty-one of the 44 COCs were identified as risk drivers for benthic invertebrates because concentrations of these 41 COCs in surface sediment exceed the SQS criteria at one or more locations (Table 3-16).
- For benthic invertebrates living in intertidal and subtidal sediment, sediment contaminant concentrations and site-specific sediment toxicity test results indicated that harmful effects are not likely in approximately 75% of the LDW area based on the RI dataset (or 82% based on the FS dataset).[14] There is a higher likelihood for adverse effects in approximately 7% of the LDW area (4% based on the FS dataset), where contaminant concentrations or biological effects were found to be in excess of the CSL criteria. The remaining 18% of the LDW study area (14% based on the FS dataset) had contaminant concentrations or biological effects between the SQS and CSL, indicating that risks to benthic invertebrate communities are less certain in these areas than in areas with contaminant concentrations greater than one or more CSL values. The samples with concentrations that exceeded the SMS criteria are geospatially concentrated in multiple areas that cumulatively represent about 25% of the LDW sediment surface (18% based on the FS dataset).
- Sediment RBTCs for the benthic invertebrate community were established at the SQS and CSL criteria of the SMS.
- In consultation with EPA and Ecology, PCBs were identified as a risk driver for river otters (Tables 3-2 and 3-16). The wildlife sediment RBTCs for PCBs were calculated using the food web model based on seafood consumption by river otters. No other risk drivers were identified for crabs, fish, or other wildlife (Table 3-2).
- The highest risks to people were associated with the consumption of seafood, including resident fish, crabs, and clams (Tables 3-4a and 3-4b). Lower risks were associated with activities that involve direct contact with sediment, such as clamming, beach play, and netfishing (Tables 3-6a and 3-6b).
- Total PCBs, arsenic, cPAHs, and dioxins/furans were identified as risk drivers for human health (Tables 3-8 and 3-16).

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[14] Estimated areas with exceedances were based on the RI or FS baseline surface sediment datasets (as specified in text) and Thiessen polygons.

- For total PCBs, sediment RBTCs ranged from 7.3 to 185 µg/kg dw for the 1 in 10,000 (1 × 10^{-4}) excess cancer risk level for the three RME scenarios (Table 3-9). RBTCs for the 10^{-5} and 10^{-6} risk levels and the non-cancer RBTC for total PCBs for the RME seafood consumption scenarios were less than 1 µg/kg dw.
- For arsenic and cPAHs, 95% or more of the risk associated with seafood consumption is attributable to the consumption of clams. Because the clam tissue-to-sediment contaminant concentration relationships in the RI/FS data were too uncertain to support developing quantitative sediment RBTCs for these risk drivers, sediment RBTCs were not derived. Clam tissue and sediment relationships for arsenic and cPAHs and methods to reduce concentrations of these contaminants in clam tissue will be subject to further study prior to sediment remediation.
- For dioxins/furans, sediment RBTCs for seafood consumption were not calculated because risks for the LDW were assumed to be unacceptable. Also, RBTCs for those risks were assumed to be more stringent than the natural background concentrations to which they would default for final cleanup decision-making under MTCA. As a result, tissue dioxin/furan data were not collected and analyzed for specific exposure estimates. Without these data, sediment RBTCs for seafood ingestion scenarios could not be calculated. Natural background values are the sediment PRGs for dioxins/furans to address seafood consumption in this FS in lieu of risk-based RBTCs (see Section 4). If RBTCs had been calculated and they were more stringent than natural background values as was assumed, these same natural background values would be the PRGs.
- Sediment RBTCs for RME direct sediment contact scenarios were calculated for all four risk drivers and all three risk levels (Table 3-10).
- Tissue RBTCs for excess cancer risks at the three risk levels were calculated for seafood consumption scenarios for all four risk drivers; non-cancer hazard RBTCs were calculated for total PCBs and arsenic (Table 3-11). Species-specific RBTCs were also calculated for comparison with LDW and non-urban Puget Sound tissue concentrations (Tables 3-13 through 3-15; Figures 3-3 through 3-6).

The risk screening process used to identify COPCs, COCs, and risk drivers for human health and ecological receptors is summarized in Table 3-16. The COCs not selected as risk drivers are evaluated in Section 9 to assess the potential for risk reduction following remedial actions.

Table 3-1 Summary of COCs and Selection of Risk Drivers for Benthic Invertebrates

	SMS Criteria			No. of Detected Concentrations in Surface Sediments				
COPC	**Unit**	**SQS**	**CSL**	**> SQS, < CSL**	**> CSL**	**Benthic COC?**	**Benthic Risk Driver?**	**Rationale for Selection/Exclusion as Risk Driver**
Metals (mg/kg dw)								
Arsenic	mg/kg dw	57	93	5	8	Yes	Yes	Detected concentration(s) > SQS
Cadmium	mg/kg dw	5.1	6.7	2	11	Yes	Yes	Detected concentration(s) > SQS
Chromium	mg/kg dw	260	270	1	8	Yes	Yes	Detected concentration(s) > SQS
Copper	mg/kg dw	390	390	0	12	Yes	Yes	Detected concentration(s) > SQS
Lead	mg/kg dw	450	530	2	19	Yes	Yes	Detected concentration(s) > SQS
Mercury	mg/kg dw	0.41	0.59	14	23	Yes	Yes	Detected concentration(s) > SQS
Nickel[a]	n/a	n/a	n/a	9 (DMMP SL)	4 (DMMP ML)	Yes	No	Moderate TRV uncertainty; areas with concentrations greater than the TRV were all in planned sediment remediation areas
Silver	mg/kg dw	6.1	6.1	0	10	Yes	Yes	Detected concentration(s) > SQS
Zinc	mg/kg dw	410	960	26	16	Yes	Yes	Detected concentration(s) > SQS
PAHs (mg/kg oc)								
2-Methylnaphthalene	mg/kg oc	38	64	0	3	Yes	Yes	Detected concentration(s) > SQS
Acenaphthene	mg/kg oc	16	57	16	3	Yes	Yes	Detected concentration(s) > SQS
Acenaphthylene	mg/kg oc	66	66	0	0	No	No	No detected concentration(s) > SQS
Anthracene	mg/kg oc	220	1,200	2	0	Yes	Yes	Detected concentration(s) > SQS
Benzo(a)anthracene	mg/kg oc	110	270	9	3	Yes	Yes	Detected concentration(s) > SQS
Benzo(a)pyrene	mg/kg oc	99	210	5	3	Yes	Yes	Detected concentration(s) > SQS
Benzo(g,h,i)perylene	mg/kg oc	31	78	9	7	Yes	Yes	Detected concentration(s) > SQS
Total benzofluoranthenes	mg/kg oc	230	450	5	4	Yes	Yes	Detected concentration(s) > SQS
Chrysene	mg/kg oc	110	460	23	1	Yes	Yes	Detected concentration(s) > SQS
Dibenzo(a,h) anthracene	mg/kg oc	12	33	15	4	Yes	Yes	Detected concentration(s) > SQS
Dibenzofuran	mg/kg oc	15	58	7	3	Yes	Yes	Detected concentration(s) > SQS

Table 3-1 Summary of COCs and Selection of Risk Drivers for Benthic Invertebrates (continued)

COPC	SMS Criteria			No. of Detected Concentrations in Surface Sediments		Benthic COC?	Benthic Risk Driver?	Rationale for Selection/Exclusion as Risk Driver
	Unit	SQS	CSL	> SQS, < CSL	> CSL			
Fluoranthene	mg/kg oc	160	1,200	31	8	Yes	Yes	Detected concentration(s) > SQS
Fluorene	mg/kg oc	23	79	11	3	Yes	Yes	Detected concentration(s) > SQS
Indeno(1,2,3-cd) pyrene	mg/kg oc	34	88	15	8	Yes	Yes	Detected concentration(s) > SQS
Naphthalene	mg/kg oc	99	170	0	2	Yes	Yes	Detected concentration(s) > SQS
Phenanthrene	mg/kg oc	100	480	24	3	Yes	Yes	Detected concentration(s) > SQS
Pyrene	mg/kg oc	1,000	1,400	1	3	Yes	Yes	Detected concentration(s) > SQS
Total HPAH	mg/kg oc	960	5,300	21	3	Yes	Yes	Detected concentration(s) > SQS
Total LPAH	mg/kg oc	370	780	3	3	Yes	Yes	Detected concentration(s) > SQS
Phthalates (mg/kg oc)								
Bis(2-ethylhexyl) phthalate	mg/kg oc	47	78	48	58	Yes	Yes	Detected concentration(s) > SQS
Butyl benzyl phthalate	mg/kg oc	4.9	64	69	8	Yes	Yes	Detected concentration(s) > SQS
Diethyl phthalate	mg/kg oc	61	110	0	0	No	No	No detected concentration(s) > SQS
Dimethyl phthalate	mg/kg oc	53	53	0	2	Yes	Yes	Detected concentration(s) > SQS
Di-n-butyl phthalate	mg/kg oc	220	1,700	0	0	No	No	No detected concentration(s) > SQS
Di-n-octyl phthalate	mg/kg oc	58	4,500	0	0	No	No	No detected concentration(s) > SQS
Other SVOCs (mg/kg oc)								
1,2,4-Trichlorobenzene	mg/kg oc	0.81	1.8	0	1	Yes	Yes	Detected concentration(s) > SQS
1,2-Dichlorobenzene	mg/kg oc	2.3	2.3	0	3	Yes	Yes	Detected concentration(s) > SQS
1,4-Dichlorobenzene	mg/kg oc	3.1	9	0	3	Yes	Yes	Detected concentration(s) > SQS
2,4-Dimethylphenol	µg/kg dw	29	29	0	1	Yes	Yes	Detected concentration(s) > SQS
2-Methylphenol	µg/kg dw	63	63	0	0	No	No	No detected concentration(s) > SQS
4-Methylphenol	µg/kg dw	670	670	0	4	Yes	Yes	Detected concentration(s) > SQS
Benzoic acid	µg/kg dw	650	650	0	7	Yes	Yes	Detected concentration(s) > SQS

Table 3-1 Summary of COCs and Selection of Risk Drivers for Benthic Invertebrates (continued)

	SMS Criteria			No. of Detected Concentrations in Surface Sediments				
COPC	**Unit**	**SQS**	**CSL**	**> SQS, < CSL**	**> CSL**	**Benthic COC?**	**Benthic Risk Driver?**	**Rationale for Selection/Exclusion as Risk Driver**
Benzyl alcohol	µg/kg dw	57	73	2	2	Yes	Yes	Detected concentration(s) > SQS
Hexachlorobenzene	mg/kg oc	0.38	2.3	4	2	Yes	Yes	Detected concentration(s) > SQS
Hexachlorobutadiene	mg/kg oc	3.9	6.2	0	0	No	No	No detected concentration(s) > SQS
n-Nitrosodiphenylamine	mg/kg oc	11	11	0	2	Yes	Yes	Detected concentration(s) > SQS
Pentachlorophenol	µg/kg dw	360	690	1	0	Yes	Yes	Detected concentration(s) > SQS
Phenol	µg/kg dw	420	1,200	18	7	Yes	Yes	Detected concentration(s) > SQS
PCBs (mg/kg oc)								
Total PCBs	mg/kg oc	12	65	301	173	Yes	Yes	Detected concentration(s) > SQS
Pesticides								
Total DDTs [a]	n/a	n/a	n/a	1 (NOAEL)	1 (LOAEL)	Yes	No	Moderate TRV uncertainty; the 1 sample with a concentration greater than the TRV is in a planned sediment remediation area
Total chlordane [a]	n/a	n/a	n/a	19 (NOAEL)	14 (LOAEL)	Yes	No	High uncertainty in exposure data and TRV; 13 of 14 samples with LOAEL exceedances were in planned sediment remediation areas

Notes:

1. This table is derived from Table 5-6 of the RI (Windward 2010).
2. Statistics in this table were calculated using the RI baseline dataset.

a. No SMS numerical criteria were available for these contaminants. Thus, the comparison is with the DMMP SL and ML for nickel or with the NOAEL or LOAEL for total DDTs and total chlordane.

COC = contaminant of concern; CSL = cleanup screening level of SMS; DDT = dichlorodiphenyltrichloroethane; DMMP = Dredged Material Management Program; HPAH = high-molecular-weight polycyclic aromatic hydrocarbon; HQ = hazard quotient; LOAEL = lowest-observed-adverse-effect level; LPAH = low-molecular-weight polycyclic aromatic hydrocarbon; mg/kg oc = milligrams per kilogram organic carbon; ML = maximum level; n/a = not applicable; NOAEL = no-observed-adverse-effect level; oc – organic carbon; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; RI = remedial investigation; SL = screening level; SMS = Washington State Sediment Management Standards; SQS = sediment quality standard of SMS; SVOC = semivolatile organic compound; TRV = toxicity reference value

Table 3-2 Summary of COCs and Selection of Risk Drivers for Crab, Fish, and Wildlife Species

COC[a]	Receptor of Concern	NOAEL-based HQ	LOAEL-based HQ	Risk Driver?	Rationale for Selection or Exclusion as Risk Driver
Total PCBs	Crabs	**10**	**1.0**	No	Low risk estimate (LOAEL HQ equal to 1.0) and high level of uncertainty associated with TRV and exposure data.
	English Sole	**4.9 – 25**	0.98 – **5.0**	No	Exposure concentrations were within the LOAEL range. A LOAEL range was used because of the high level of uncertainty associated with the TRV.
	Pacific Staghorn Sculpin	**1.5 – 19**	0.30 – **3.8**	No	
	River Otter	**5.8**	**2.9**	Yes	LOAEL-based HQ for river otter was greater than 1.0 (HQ of 2.9), and the uncertainties associated with the exposure and effects data were relatively low.
Total PCBs and PCB TEQ	Spotted Sandpiper	**1.9 – 15**	0.18 – **1.5**	No	LOAEL-based HQs for total PCBs were less than 1.0, but equal to 1.5 for PCB TEQ. The effects data used to calculate risk estimates for total PCBs were less uncertain than those for PCB TEQ.
Cadmium	Juvenile Chinook Salmon	**5.0**	**1.0**	No	High level of uncertainty associated with the selected TRV and low risk estimates.
	English Sole	**6.1**	**1.2**	No	
	Pacific Staghorn Sculpin	**3.0 – 5.2**	0.60 – **1.0**	No	
Chromium	Spotted Sandpiper	**1.3 – 8.8**	0.26 – **1.8**	No	Elevated risks were driven by a single benthic invertebrate tissue sample (and co-located sediment was not elevated).
Copper	Spotted Sandpiper	0.62 – **1.5**	0.45 – **1.1**	No	Sediment concentrations were similar to PSAMP rural Puget Sound concentrations, and HQs will be less than 1 following planned sediment remediation in EAAs.
Lead	Spotted Sandpiper	0.58 – **19**	0.17 – **5.5**	No	Elevated risks were driven by a single benthic invertebrate tissue sample (and co-located sediment was not elevated).
Mercury	Spotted Sandpiper	**1.1 – 5.3**	0.21 – **1.0**	No	HQs will be less than 1 following planned sediment remediation in EAAs.
Vanadium	English Sole	**5.9**	**1.2**	No	High uncertainty in effects data (few toxicity studies), and sediment concentrations of vanadium in exposure areas were less than the 90th percentile vanadium concentration in PSAMP rural Puget Sound sediment.
	Pacific Staghorn Sculpin	**3.2 – 5.9**	0.65 – **1.2**	No	
	Spotted Sandpiper	**2.0 – 2.7**	**1.0 – 1.4**	No	

Notes:

1. This table is derived from Table 5-16 of the RI (Windward 2010).
2. HQs for fish are highest when more than one approach was used.
3. **Bold** identifies NOAEL-based HQs greater than 1.0 or LOAEL-based HQs greater than or equal to 1.0.

a. A contaminant was identified as a COC if the LOAEL-based HQ was greater than or equal to 1.0.

COC = contaminant of concern; EAA = early action area; HQ = hazard quotient; LOAEL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect level; PCB = polychlorinated biphenyl; PSAMP = Puget Sound Ambient Monitoring Program; RI = remedial investigation; TEQ = toxic equivalent; TRV = toxicity reference value

Table 3-3 Summary of COCs for Human Health Seafood Consumption and Direct-Contact Sediment Exposure Scenarios

COC[a]	Human Health Exposure Pathway	
	Seafood Consumption	**Direct Contact**
Total PCBs[b]	X	X
Arsenic	X	X
cPAHs	X	X
Dioxins/furans	X	X
Aldrin[c]	X	
BEHP	X	
Alpha-BHC[c]	X	
Beta-BHC[c]	X	
Carbazole[c]	X	
Total chlordane[c]	X	
Total DDTs[c]	X	
Dieldrin[c]	X	
Gamma-BHC[c]	X	
Heptachlor[c]	X	
Heptachlor epoxide[c]	X	
Hexachlorobenzene[c]	X	
Pentachlorophenol	X	
TBT	X	
Toxaphene[c]		X
Vanadium	X	

Notes:

a. Contaminants with an excess cancer risk greater than 1 × 10^{-6} or a non-cancer HQ greater than 1 for at least one RME seafood consumption scenario were identified as COCs.

b. PCB TEQ was also identified as having risks greater than 1 × 10^{-6} for at least one RME seafood consumption scenario and at least one RME direct contact scenario.

c. These contaminants were qualified as tentatively identified compounds at estimated concentrations (JN-qualified), indicating uncertainty regarding both their presence and concentration.

BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; COC = contaminant of concern; cPAH = carcinogenic polycyclic aromatic hydrocarbon; DDT = dichlorodiphenyltrichloroethane; HQ = hazard quotient; PCB = polychlorinated biphenyl; RME = reasonable maximum exposure; TBT = tributyltin; TEQ = toxic equivalent

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

COC	Scenarios Evaluated in the FS			Scenarios for Informational Purposes							
								Adult One Meal per Month			
	Adult Tribal RME (Tulalip Data)[a]	**Child Tribal RME (Tulalip Data)[a]**	**Adult API RME**	**Adult Tribal CT (Tulalip Data)[a]**	**Child Tribal CT (Tulalip Data)[a]**	**Adult Tribal (Suquamish Data)**	**Adult API CT**	**Benthic Fish**	**Clam**	**Crab**	**Pelagic Fish**
Arsenic (inorganic)[b]	2×10^{-3}	3×10^{-4}	7×10^{-4}	7×10^{-5}	3×10^{-5}	2×10^{-2}[c]	1×10^{-5}	4×10^{-7}	1×10^{-4}	3×10^{-6}	6×10^{-6}
BEHP	6×10^{-6}	1×10^{-6}	2×10^{-6}	2×10^{-7}	7×10^{-8}	4×10^{-5}	3×10^{-8}	8×10^{-7}	8×10^{-8}	8×10^{-8}[d]	1×10^{-6}
cPAHs[e]	8×10^{-5}	8×10^{-5}	3×10^{-5}	4×10^{-6}	9×10^{-6}	8×10^{-4}	8×10^{-7}	2×10^{-7}	7×10^{-6}	2×10^{-7}	3×10^{-7}
Dioxin/furans[f]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
PCB TEQ	1×10^{-3}	2×10^{-4}	4×10^{-4}	5×10^{-5}	2×10^{-5}	7×10^{-3}	7×10^{-6}	8×10^{-5}	2×10^{-5}	2×10^{-5}	2×10^{-4}
Total PCBs	2×10^{-3}	3×10^{-4}	5×10^{-4}	6×10^{-5}	3×10^{-5}	1×10^{-2}[c]	8×10^{-6}	1×10^{-4}	5×10^{-5}	2×10^{-5}	2×10^{-4}
Pentachlorophenol[b]	9×10^{-5}[g]	2×10^{-5}[g]	2×10^{-5}	2×10^{-6}[g]	7×10^{-7}[g]	5×10^{-4}[g]	3×10^{-7}	2×10^{-5}[d]	1×10^{-6}[d]	2×10^{-6}[d]	1×10^{-5}
Subtotal (excluding PCB TEQ)	**4×10^{-3}**	**7×10^{-4}**	**1×10^{-3}**	**1×10^{-4}**	**7×10^{-5}**	**3×10^{-2}**	**2×10^{-5}**	**1×10^{-4}**	**2×10^{-4}**	**3×10^{-5}**	**2×10^{-4}**
Subtotal (excluding total PCBs)	**3×10^{-3}**	**6×10^{-4}**	**1×10^{-3}**	**1×10^{-4}**	**6×10^{-5}**	**3×10^{-2}**	**2×10^{-5}**	**1×10^{-4}**	**1×10^{-4}**	**3×10^{-5}**	**2×10^{-4}**
Tentatively Identified Compounds (JN-qualified)											
Aldrin	5×10^{-5}[g]	8×10^{-6}[g]	1×10^{-5}	1×10^{-6}[g]	6×10^{-7}[g]	2×10^{-4}	2×10^{-7}	3×10^{-6}[d]	8×10^{-7}[d]	3×10^{-6}[d]	3×10^{-6}
alpha-BHC	2×10^{-5}[g]	3×10^{-6}[g]	3×10^{-6}	5×10^{-7}[g]	2×10^{-7}[g]	6×10^{-5}	6×10^{-8}	1×10^{-6}	1×10^{-7}	1×10^{-6}[d]	1×10^{-6}
beta-BHC	6×10^{-6}[g]	1×10^{-6}[g]	1×10^{-6}	2×10^{-7}[g]	1×10^{-7}[g]	3×10^{-5}	3×10^{-8}	3×10^{-7}	1×10^{-7}	3×10^{-7}[d]	6×10^{-7}
Carbazole	4×10^{-5}	8×10^{-6}	1×10^{-5}	9×10^{-7}	4×10^{-7}	2×10^{-4}	8×10^{-8}	1×10^{-6}[d]	9×10^{-8}[d]	1×10^{-6}[d]	1×10^{-5}
Total chlordane	6×10^{-6}	1×10^{-6}	2×10^{-6}	2×10^{-7}	8×10^{-8}	3×10^{-5}	3×10^{-8}	3×10^{-7}	7×10^{-8}	7×10^{-8}	1×10^{-6}
Total DDTs	2×10^{-5}	4×10^{-6}	6×10^{-6}	1×10^{-6}	4×10^{-7}	1×10^{-4}	1×10^{-7}	1×10^{-6}	2×10^{-7}	4×10^{-7}	4×10^{-6}
Dieldrin	1×10^{-4}	3×10^{-5}	5×10^{-5}	3×10^{-6}	1×10^{-6}	1×10^{-3}	4×10^{-7}	3×10^{-6}[d]	9×10^{-6}	3×10^{-6}	3×10^{-6}[d]
gamma-BHC	5×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-7}	5×10^{-8}	3×10^{-5}	1×10^{-8}	2×10^{-7}[d]	1×10^{-7}	2×10^{-7}	1×10^{-7}
Heptachlor	1×10^{-5}[g]	3×10^{-6}[g]	3×10^{-6}	4×10^{-7}[g]	2×10^{-7}[g]	6×10^{-5}	4×10^{-8}	7×10^{-7}[d]	1×10^{-7}[d]	7×10^{-7}[d]	2×10^{-6}

Table 3-4a Summary of Estimated Excess Cancer Risks for the Seafood Consumption Scenarios (continued)

	Scenarios Evaluated in the FS			**Scenarios for Informational Purposes**							
								Adult One Meal per Month			
COC	**Adult Tribal RME (Tulalip Data)[a]**	**Child Tribal RME (Tulalip Data)[a]**	**Adult API RME**	**Adult Tribal CT (Tulalip Data)[a]**	**Child Tribal CT (Tulalip Data)[a]**	**Adult Tribal (Suquamish Data)**	**Adult API CT**	**Benthic Fish**	**Clam**	**Crab**	**Pelagic Fish**
Heptachlor epoxide	3×10^{-5}	6×10^{-6}	9×10^{-6}	1×10^{-6}	5×10^{-7}	2×10^{-4}	1×10^{-7}	1×10^{-6} [d]	6×10^{-7}	9×10^{-7}	4×10^{-6}
Hexachlorobenzene	1×10^{-5}	2×10^{-6}	2×10^{-6}	2×10^{-7}	1×10^{-7}	4×10^{-5}	3×10^{-8}	6×10^{-7}	6×10^{-8}	6×10^{-7}	9×10^{-7}
Subtotal	**3×10^{-4}**	**7×10^{-5}**	**1×10^{-4}**	**9×10^{-6}**	**4×10^{-6}**	**2×10^{-3}**	**1×10^{-6}**	**1×10^{-5}**	**1×10^{-5}**	**1×10^{-5}**	**3×10^{-5}**
Total excess cancer risk (excluding PCB TEQ)	**4×10^{-3}**	**8×10^{-4}**	**1×10^{-3}**	**1×10^{-4}**	**7×10^{-5}**	**3×10^{-2}**	**2×10^{-5}**	**1×10^{-4}**	**2×10^{-4}**	**4×10^{-5}**	**2×10^{-4}**
Total excess cancer risk (excluding total PCBs)	**3×10^{-3}**	**7×10^{-4}**	**1×10^{-3}**	**1×10^{-4}**	**6×10^{-5}**	**3×10^{-2}**	**2×10^{-5}**	**1×10^{-4}**	**1×10^{-4}**	**4×10^{-5}**	**2×10^{-4}**

Notes:

a. The excess cancer risk estimates reported here differ slightly from those reported in Appendix B (the HHRA) (Windward 2007b) and Section 6 of the RI (Windward 2010). The apportionment of shellfish (i.e., the amount of crab consumed relative to other shellfish but not the total quantity consumed) for scenarios based on the Tulalip Tribes survey was updated in response to a correction provided by EPA. The influence of this correction on the total risk estimates is relatively minor. This change and its impact on risk estimates were described in detail in an erratum (Windward 2009) to the HHRA (Windward 2007b).

b. No mussel data were available for this COC. When the chronic daily intake and risk values were calculated, the portion of seafood consumption that had been assigned to mussels was divided proportionally among the remaining consumption categories.

c. Because the excess cancer risk is greater than or equal to 0.01, risk was calculated using the exponential equation in EPA (1989).

d. There were no detected values in this seafood category. Chronic daily intake and risk estimate were based on one-half the maximum reporting limit.

e. cPAHs are presented as benzo(a)pyrene TEQs. Data used in the risk characterization were only from 2004 because of high reporting limits in historical data. All cPAH data were analyzed in the uncertainty analysis (Appendix B of the RI, Section B.6, Windward 2010). Because of the potential for the increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005a), the risk estimate for children for cPAHs was based on dose adjustments across the 0-to-6-year-old age range of children. See the HHRA in Appendix B of the RI, Section B.5.1 (Windward 2010), for more information.

f. Tissue data for dioxins/furans were not collected. Thus, the calculated total risk, which does not include risks from dioxins/furans, is underestimated to an unknown degree.

g. Greater than 50% of the risk associated with this contaminant is derived from seafood categories with no detected values.

API = Asian and Pacific Islander; BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; COC = contaminant of concern; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CT = central tendency; DDT = dichlorodiphenyltrichloroethane; EPA = U.S. Environmental Protection Agency; FS = feasibility study; HHRA = human health risk assessment; n/a = not available; PCB = polychlorinated biphenyl; RI = remedial investigation; RME = reasonable maximum exposure; TEQ = toxic equivalent

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

Contaminants and Hazard Indices	Scenarios Evaluated in the FS			Scenarios for Informational Purposes							
								Adult One Meal per Month			
	Adult Tribal RME (Tulalip Data)[a]	Child Tribal RME (Tulalip Data)[a]	Adult API RME	Adult Tribal CT (Tulalip Data)[a]	Child Tribal CT (Tulalip Data)[a]	Adult Tribal (Suquamish Data)	Adult API CT	Benthic Fish	Clam	Crab	Pelagic Fish
Hazard Quotients for COPCs with HQs > 1 for One or More Scenarios[b]											
Arsenic (inorganic)[c]	4	8	3	0.4	0.7	38	0.2	0.002	0.7	0.01	0.03
Chromium[d]	0.2	0.4	0.1	0.02	0.04	2	0.01	0.002	0.03	0.006	0.007
Mercury[e]	0.5	1	0.3	0.07	0.1	2	0.02	0.06	0.02	0.07	0.04
Total PCBs	40	87	29	4	8	274	2	6	3	1	10
TBT (as ion)	2	3	1	0.2	0.4	15	0.1	0.002	0.3	0.02	0.06
Vanadium	0.9	2	0.8	0.1	0.3	9	0.07	0.01	0.2	0.01	0.06
Hazard Indices by Effect (Endpoint)[b]											
HI for cardiovascular endpoint[f]	5	10	4	0.5	1	47	0.3	0.01	0.9	0.02	0.09
HI for developmental endpoint[g]	41	88	29	4	8	276	2	6	3	1	10
HI for hematologic endpoint[h]	0.2	0.5	0.2	0.03	0.05	2	0.01	0.006	0.03	0.01	0.009
HI for immunological endpoint[i]	42	90	30	4	8	289	2	6	3	1	10
HI for kidney endpoint[j]	0.4	0.9	0.3	0.05	0.1	2	0.02	0.03	0.03	0.04	0.04
HI for liver endpoint[k]	1	2	0.8	0.1	0.3	7	0.05	0.1	0.1	0.09	0.3
HI for neurological endpoint[l]	41	88	29	4	8	276	2	6	3	1	10
HI for dermal endpoint[m]	4	8	3	0.4	0.7	38	0.2	0.01	0.7	0.02	0.06

Notes:

a. The non-cancer HIs reported here differ slightly from those reported in the HHRA (Windward 2007b) and Section 6 of the RI (Windward 2010). The apportionment of shellfish (i.e., the amount of crab consumed relative to other shellfish but not the total quantity consumed) for scenarios based on the Tulalip Tribes survey was updated in response to a correction provided by EPA. The influence of this correction on the total risk estimates is relatively minor. This change and its impact on risk estimates are described in detail in an erratum (Windward 2009) to the HHRA (Windward 2007b).

b. Hazard indices include risks associated with all COPCs by endpoint. However, only those COPCs with an HQ greater than or equal to 1 for at least one RME scenario are listed in this table.

Table 3-4b Summary of Estimated Non-cancer Hazards for the Seafood Consumption Scenarios (continued)

c. No mussel data were available for this COPC. When calculating the risk values, the portion of seafood consumption that had been assigned to mussels was divided proportionally among the remaining consumption categories.

d. Chromium HQ did not exceed 1 for any RME scenario, so it is not a COC. It is included in this table because the HQ exceeded 1 for the adult tribal (Suquamish data) scenario.

e. Mercury HQ did not exceed 1 for any RME scenario, so it is not a COC. It is included in this table because the HQ exceeded 1 for the adult tribal (Suquamish data) scenario.

f. Cardiovascular endpoint is for arsenic and vanadium.

g. Developmental endpoint is for total PCBs and mercury.

h. Hematologic endpoint is for antimony and zinc. Individual HQs for these COPCs are not presented because none are equal to or greater than 1 for any scenario.

i. Immunological endpoint is for total PCBs and TBT.

j. Kidney endpoint is for 4-methylphenol, cadmium, copper, gamma-BHC, and pentachlorophenol. Individual HQs for these COPCs are not presented because none are equal to or greater than 1 for any scenario.

k. Liver endpoint is for 4-methylphenol, aldrin, alpha-BHC, beta-BHC, BEHP, butyl benzyl phthalate, chlordane, copper, total DDTs, dieldrin, endrin, endrin aldehyde, gamma-BHC, heptachlor, heptachlor epoxide, hexachlorobenzene, and pentachlorophenol. Individual HQs for these COPCs are not presented because none are equal to or greater than 1 for any scenario.

l. Neurological endpoint is for 4-methylphenol, mercury, and total PCBs. Individual HQs for 4-methylphenol are not presented because none are equal to or greater than 1 for any scenario.

m. Dermal endpoint is for 4-methylphenol and arsenic. Individual HQs for 4-methylphenol are not presented because none are equal to or greater than 1 for any scenario.

API = Asian and Pacific Islander; BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; COC = contaminant of concern; COPC = contaminant of potential concern; CT = central tendency; DDT = dichlorodiphenyltrichloroethane; EPA = U.S. Environmental Protection Agency; HI = hazard index; HQ = hazard quotient; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; RI = remedial investigation; RME = reasonable maximum exposure; TBT = tributyltin

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

COC	Adult Tribal RME (Tulalip Data)[a]		Child Tribal RME (Tulalip Data)[a]		Adult API RME	
	Excess Cancer Risk (% of Total)	Percent of Risk by Seafood Consumption Category	Excess Cancer Risk (% of Total)	Percent of Risk by Seafood Consumption Category	Excess Cancer Risk (% of Total)	Percent of Risk by Seafood Consumption Category
Arsenic (inorganic)	2×10^{-3} (44%)	97% clams; 1.3% crab EM; 1.1% crab WB; 0.8% pelagic; 0.06% benthic fillet	3×10^{-4} (40%)	97% clams; 1.3% crab EM; 1.1% crab WB; 0.8% pelagic; 0.06% benthic fillet	7×10^{-4} (50%)	98% clams; 0.9% crab WB; 0.7% pelagic; 0.4% crab EM; 0.05% benthic WB; 0.02% benthic fillet
cPAHs	8×10^{-5} (2%)	96% clams; 2.1% crab EM; 0.9% crab WB; 0.8% pelagic; 0.5% benthic fillet	8×10^{-5} (11%)	96% clams; 2.1% crab EM; 0.9% crab WB; 0.8% pelagic; 0.5% benthic fillet	3×10^{-5} (3%)	98% clams; 0.8% crab WB; 0.8% pelagic; 0.6% crab EM; 0.2% benthic WB; 0.2% benthic fillet
Total PCBs	2×10^{-3} (43%)	39% clams; 23% pelagic; 15% crab WB; 14% benthic fillet; 9% crab EM, 0.05% mussels	3×10^{-4} (39%)	39% clams; 23% pelagic; 15% crab WB; 14% benthic fillet; 9% crab EM, 0.05% mussels	5×10^{-4} (38%)	47% clams; 25% pelagic; 15% crab WB; 6.5% benthic fillet; 3% crab EM; 3% benthic WB; 0.5% mussels
Other COCs (BEHP, PCP, aldrin, alpha-BHC, beta-BHC, carbazole, chlordane, total DDTs, dieldrin, gamma-BHC, heptachlor, heptachlor epoxide, and hexachlorobenzene)[b]	4×10^{-4} (11%)	Average contribution: 29% crab EM, 29% pelagic, 20% clam, 14% benthic fillet, 9% crab WB, 0.3% mussels	8×10^{-5} (10%)	Average contribution: 29% crab EM, 29% pelagic, 20% clam, 14% benthic fillet, 9% crab WB, 0.3% mussels	1×10^{-4} (9%)	Average contribution: 35% pelagic, 29% clam, 13% crab EM, 11% crab WB, 7% benthic fillet, 3% mussels, 2% benthic WB
Total excess cancer risk and main contributors to the total excess cancer risk[c, d, e]	**4×10^{-3}**	**42% – arsenic in clams** **17% – PCBs in clams** **10% – PCBs in pelagic fish** **6% – PCBs in WB crab** **6% – PCBs in benthic fillet** **19% – other**	**8×10^{-4}**	**39% – arsenic in clams** **15% – PCBs in clams** **10% – cPAHs in clams** **9% – PCBs in pelagic fish** **6% – PCBs in WB crab** **5% – PCBs in benthic fillet** **16% – other**	**1×10^{-3}**	**49% – arsenic in clams** **18% – PCBs in clams** **10% – PCBs in pelagic fish** **6% – PCBs in WB crab** **17% – other**

Notes:

a. The excess cancer risk estimates reported here differ slightly from those reported in the HHRA (Windward 2007b) and Section 6 of the RI (Windward 2010). The apportionment of shellfish (i.e., the amount of crab consumed relative to other shellfish but not the total quantity consumed) for scenarios based on the Tulalip Tribes survey was updated in response to a correction provided by EPA. The influence of this correction on the total risk estimates is relatively minor. This change and its impact on risk estimates were described in detail in an erratum (Windward 2009) to the HHRA (Windward 2007b).

b. Top contributors were dieldrin (approximately 3 to 4%) and pentachlorophenol (approximately 1.5 to 2.5%). All other COCs contributed less than 1.5%.

c. Seafood consumption category-COC combinations contributing greater than 5% of the total risk are listed separately. All other combinations are included in the “other” category.

d. Tissue data for dioxins/furans were not available at the time that the HHRA was finalized. After the HHRA had been finalized, data became available for six skin-off English sole fillets from a May 2007 PSAMP sampling effort near Kellogg Island (Gries 2008). Based on these data, the risks associated with dioxins/furans would be 6×10^{-5} for the adult tribal RME scenario (Tulalip data), 1×10^{-5} for the child tribal RME scenario (Tulalip data), and 2×10^{-5} for the adult API RME scenario. These risks for dioxins/furans were calculated based on the assumption that all seafood in the market basket diet for the RME scenarios had the same dioxin/furan concentrations as those in the fillets of English sole collected in 2007 near Kellogg Island.

e. Total risks are underestimated because dioxin/furan risks are not included (see Section 3.2.1). However, because excess cancer risks are presented as one significant figure, the total risk estimate may not change because the risk estimate from dioxins/furans may be an order of magnitude or more lower than the total risk estimate based on total PCBs, arsenic, and cPAHs.

API = Asian and Pacific Islander; BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; cPAH = carcinogenic polycyclic aromatic hydrocarbon; COC = contaminant of concern; DDT = dichlorodiphenyltrichloroethane; EM = edible meat; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; PCP = pentachlorophenol; PSAMP = Puget Sound Ambient Monitoring Program; RME = reasonable maximum exposure; WB = whole body

Table 3-6a Summary of Estimated Excess Cancer Risks for the Direct Sediment Contact Scenarios using the RI Baseline Dataset

COC	Netfishing RME	Beach Play RME								Tribal Clamming RME
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	
Risk Drivers										
Arsenic	6×10^{-6}	5×10^{-6}	7×10^{-6}	4×10^{-6}	4×10^{-6}	3×10^{-6}	3×10^{-6}	4×10^{-6}	3×10^{-6}	2×10^{-5}
cPAHs[a]	1×10^{-6}	1×10^{-5}	4×10^{-5}	3×10^{-5}	8×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-6}	4×10^{-6}	5×10^{-6}
Dioxins/furans	2×10^{-5} [b]	n/a	n/a	n/a	1×10^{-5}	8×10^{-8}	n/a	6×10^{-8}	n/a	1×10^{-4}[c]
PCB TEQ	4×10^{-6}	4×10^{-9}	3×10^{-7}	n/a	9×10^{-6}	1×10^{-7}	3×10^{-7}	3×10^{-8}	8×10^{-8}	3×10^{-5}
Total PCBs	2×10^{-6} [b]	7×10^{-8}	1×10^{-7}	1×10^{-7}	6×10^{-6}	1×10^{-7}	5×10^{-7}	1×10^{-7}	1×10^{-7}	8×10^{-6} [d]
Subtotal (excluding PCB TEQ)	**3×10^{-5}**	**2×10^{-5}**	**5×10^{-5}**	**3×10^{-5}**	**3×10^{-5}**	**8×10^{-6}**	**9×10^{-6}**	**5×10^{-6}**	**7×10^{-6}**	**1×10^{-4}**
Subtotal (excluding total PCBs)	**3×10^{-5}**	**2×10^{-5}**	**5×10^{-5}**	**3×10^{-5}**	**3×10^{-5}**	**8×10^{-6}**	**8×10^{-6}**	**5×10^{-6}**	**7×10^{-6}**	**2×10^{-4}**
Tentatively Identified Compounds (JN-qualified)										
Toxaphene	2×10^{-6}	1×10^{-8}	7×10^{-9}	2×10^{-8}	2×10^{-7}	1×10^{-7}	1×10^{-8}	1×10^{-8}	1×10^{-8}	6×10^{-6}
Total excess cancer risk across both exposure routes[c] (excluding PCB TEQ)	**3×10^{-5}**	**2×10^{-5}**	**5×10^{-5}**	**3×10^{-5}**	**3×10^{-5}**	**8×10^{-6}**	**9×10^{-6}**	**5×10^{-6}**	**7×10^{-6}**	**1×10^{-4}**
Total excess cancer risk across both exposure routes[e] (excluding total PCBs)	**3×10^{-5}**	**2×10^{-5}**	**5×10^{-5}**	**3×10^{-5}**	**3×10^{-5}**	**8×10^{-6}**	**8×10^{-6}**	**5×10^{-6}**	**7×10^{-6}**	**2×10^{-4}**

Notes:

a. cPAHs are presented as benzo(a)pyrene TEQs. Because of the potential for the increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005a), the risk estimate for the beach play RME for cPAHs was based on dose adjustments across the 0-to-6-year-old age range of children. See Section B.5.1 of the HHRA (Windward 2007b) for more information.

b. When risks were recalculated using the FS dataset, the dioxin/furan risk associated with netfishing was 3×10^{-6}.

c. When risks were recalculated using the FS dataset, the dioxin/furan risk associated with clamming was 5×10^{-5}.

d. The exposure point concentration for netfishing used for this risk estimate was based on an arithmetic upper confidence limit on the mean, which is expected to overestimate exposure because of spatially biased sampling. The arithmetic mean was greater than the spatially-weighted mean (developed using Thiessen polygons) by a factor of approximately 5.

e. Total excess cancer risks include the risks associated with all COCs. However, only those COCs with an excess cancer risk greater than or equal to 1×10^{-6} for at least one scenario are listed in this table. Non-cancer effects are not expected from direct contact exposures because no thresholds were exceeded.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; COC = contaminant of concern; EPA = U.S. Environmental Protection Agency; FS = feasibility study; HHRA = human health risk assessment; n/a = not available; PCB = polychlorinated biphenyl; RI = remedial investigation; RME = reasonable maximum exposure; TEQ = toxic equivalent

Table 3-6b Summary of Estimated Excess Cancer Risks for the Direct Sediment Contact Beach Play Scenarios Using the FS Baseline Dataset

COC	Beach Play RME[a]												
	Area 1	**Area 2**	**Area 3**	**Area 4**	**Area 4 Modified[b] without Inlet**	**Area 4 Modified[b] Inlet Only**	**Area 5**	**Area 5 Modified[c] North**	**Area 5 Modified[c] South**	**Area 6**	**Area 7**	**Area 8**	**Duwamish Waterway Park**
Arsenic	5×10^{-6}	6×10^{-6}	4×10^{-6}	4×10^{-6}	3×10^{-6}	1×10^{-5}	3×10^{-6}	6×10^{-6}	3×10^{-6}	3×10^{-5}	3×10^{-6}	3×10^{-6}	1×10^{-6}
cPAHs[d]	4×10^{-6}	8×10^{-5}	1×10^{-5}	1×10^{-5}	9×10^{-6}	4×10^{-5}	3×10^{-5}	4×10^{-5}	1×10^{-6}	8×10^{-5}	1×10^{-6}	3×10^{-6}	7×10^{-7}
Dioxins/furans	1×10^{-7}	3×10^{-6}	1×10^{-7}	1×10^{-5}	6×10^{-7}	2×10^{-5}	1×10^{-6}	1×10^{-6}	2×10^{-7}	3×10^{-7}	1×10^{-7}	1×10^{-7}	2×10^{-7}
Total PCBs	3×10^{-8}	1×10^{-7}	1×10^{-7}	6×10^{-4}	1×10^{-6}	3×10^{-3}	1×10^{-7}	3×10^{-7}	1×10^{-7}	5×10^{-7}	5×10^{-8}	6×10^{-8}	1×10^{-7}
Total excess cancer risk[e]	**9×10^{-6}**	**9×10^{-5}**	**1×10^{-5}**	**6×10^{-4}**	**1×10^{-5}**	**3×10^{-3}**	**3×10^{-5}**	**5×10^{-5}**	**4×10^{-6}**	**1×10^{-4}**	**4×10^{-6}**	**6×10^{-6}**	**2×10^{-6}**

Notes:

a. EPCs used for risk estimates are presented in Appendix B along with details regarding the calculation of the EPCs.

b. Beach 4 was divided into two parts: Area 4 modified without inlet excludes the inlet at RM 2.2W; Area 4 modified – inlet only includes only the inlet at RM 2.2W. See Figure 3-1.

c. Beach 5 was divided into two parts: Area 5 modified – north includes only the northernmost beach area and Area 5 modified – south includes only the two southernmost beach areas and excludes the northerly section. See Figure 3-1.

d. cPAHs are presented as benzo(a)pyrene TEQs. Because of the potential for the increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005a), the risk estimate for beach play RME for cPAHs was based on dose adjustments across the 0-to-6-year-old age range of children. See Section B.5.1 of the HHRA (Windward 2007b) for more information.

e. The total excess cancer risk includes only those COCs presented in this table. In the HHRA (Windward 2007b), risks from toxaphene, the other COC, made up 1% or less of the total excess cancer risk for any given assumed beach play area, and thus if the risk estimate for this other COC was added, it is unlikely that the total risk estimates presented here would change.

COC = contaminant of concern; cPAH = carcinogenic polycyclic aromatic hydrocarbon; EPC = exposure point concentration; FS = feasibility study; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; RM = river mile; RME = reasonable maximum exposure; TEQ = toxic equivalent

Table 3-7 Sum of Estimated Excess Cancer Risks across Related Scenarios as Reported in the RI

Activity	Excess Cancer Risk[a]
Adult Tribal Fishing Scenarios	
Netfishing RME[b]	3×10^{-5}
Swimming[c]	$<1 \times 10^{-6}$
Adult tribal RME seafood consumption based on Tulalip data[d]	4×10^{-3}
Sum of risk across scenarios	$\mathbf{4 \times 10^{-3}}$
Child Scenarios[e]	
Beach play RME – Area 2[f]	5×10^{-5}
Swimming[c]	$<1 \times 10^{-6}$
Subtotal for beach play RME and swimming	$\mathbf{5 \times 10^{-5}}$
Child tribal RME seafood consumption based on Tulalip data[d]	8×10^{-4}
Sum of risk across scenarios	$\mathbf{9 \times 10^{-4}}$
Adult Tribal RME Clamming Scenarios	
Tribal clamming RME – 120 days per year	1×10^{-4}
Swimming[c]	$<1 \times 10^{-6}$
Adult tribal RME seafood consumption based on Tulalip data[d]	4×10^{-3}
Sum of risk across scenarios	$\mathbf{4 \times 10^{-3}}$

Notes:

a. All non-swimming risk estimates are presented in the HHRA (Windward 2007b); for each scenario, total excess cancer risk estimates excluding PCB TEQ were used because these were equal to or higher than total excess cancer risk estimates excluding total PCBs.

b. Although EPA guidance generally discourages summing risk estimates from multiple RME scenarios, risks for the RME netfishing scenario, rather than the netfishing central tendency scenario, were added to the RME seafood consumption scenario to account for the fact that RME seafood consumption and RME netfishing may be practiced by tribal members simultaneously.

c. Adult and child swimming risk estimates as reported by King County for Elliott Bay and the Duwamish River for medium exposure assumptions (12 events per year for adults or children aged 1 to 6) (King County 1999a). Exposure pathways consisted of dermal contact and incidental sediment ingestion of water during swimming. Risks were estimated based on total PCB concentrations of 14.4 ng/L in the LDW originally modeled by King County (King County 1999a). PCB congener data from samples collected from the LDW by King County in 2005 indicate that this modeled estimate is likely an overestimate of actual total PCB concentrations, which were no greater than 3.14 ng/L during low-flow sampling conducted in August 2005 (Mickelson and Williston 2006). These results indicate that the risk estimates for the swimming scenario presented by King County in the water quality assessment (King County 1999a) are also likely overestimated.

d. The excess cancer risk estimates reported here differ slightly from those reported in the HHRA (Windward 2007b) and Section 6 of the RI (Windward 2010). The apportionment of shellfish (i.e., the amount of crab consumed relative to other shellfish) for scenarios based on the Tulalip Tribes survey was updated in response to a correction provided by EPA. The influence of this correction on the total risk estimates is relatively minor. This change and its impact on risk estimates are described in detail in an erratum (Windward 2009) to the HHRA (Windward 2007b).

e. Child scenarios include the child tribal RME seafood consumption estimate based on 40% of the total adult tribal RME seafood consumption based on Tulalip data, which is considered protective of non-tribal children.

f. Area 2 is included because it had the highest risk estimate among the individual beach play scenarios evaluated for the RI (Windward 2010) (Table 3-6a). Note that when beach play risks were calculated using the FS dataset (see Table 3-6b), risk estimates for Area 2 were no longer the highest among the assumed beach play areas.

EPA = U.S. Environmental Protection Agency; FS = feasibility study; HHRA = human health risk assessment; LDW = Lower Duwamish Waterway; PCB = polychlorinated biphenyl; RI = remedial investigation; RME = reasonable maximum exposure; TEQ = toxic equivalent

Table 3-8 Summary of COCs and Selection of Risk Drivers for Human Health Exposure Scenarios

COC	Risk Driver?	Maximum RME Risk Estimate[a]	Rationale for Selection/Exclusion as Risk Driver
Seafood Consumption Scenarios			
Inorganic arsenic	Yes	2×10^{-3}	Risk magnitude, percent contribution to the total excess cancer risk (29%), and high detection frequency in tissue samples (100%).
cPAHs	Yes	8×10^{-5}	Risk magnitude and high detection frequency in tissue samples (72%).
PCBs	Yes	2×10^{-3}	Risk magnitude, high percent contribution to the total excess cancer risk (58%), and high detection frequency in tissue samples (97%).
Dioxins/furans	Yes	nd	No dioxin/furan tissue data were available. However, because excess cancer risks were assumed to be unacceptably high, dioxins/furans were identified as a risk driver.
Bis(2-ethylhexyl) phthalate	No	6×10^{-6}	Low percent contribution to the total excess cancer risk (less than or equal to 3%) and rarely detected in tissue samples (particularly when samples were re-analyzed to evaluate the effect on RLs of analytical dilutions in the initial analysis).
Pentachlorophenol	No	9×10^{-5}	
Tributyltin	No	HQ = 3	HQs for these metals were only slightly greater than 1 (only for the child tribal RME scenario). Ingestion rates used for this scenario are uncertain.
Vanadium	No	HQ = 2	
Aldrin	No	5×10^{-5}	All organochlorine pesticides were low contributors to the total excess cancer risk (less than or equal to 3% of the total risk). In addition, because of analytical interference of these contaminants with PCBs, much of the tissue data for these contaminants were qualified JN, which indicates "the presence of an analyte that has been 'tentatively identified,' and the associated numerical value represents its approximate concentration" (EPA 1999c). The JN-qualified organochlorine pesticide results are highly uncertain and likely biased high.
alpha-BHC	No	2×10^{-5}	
beta-BHC	No	6×10^{-6}	
Carbazole	No	4×10^{-5}	
Total chlordane	No	6×10^{-6}	
Total DDTs	No	2×10^{-5}	
Dieldrin	No	1×10^{-4}	
gamma-BHC	No	5×10^{-6}	
Heptachlor	No	1×10^{-5}	
Heptachlor epoxide	No	3×10^{-5}	
Hexachlorobenzene	No	1×10^{-5}	
Direct Sediment Exposure Scenarios			
Inorganic arsenic	Yes	2×10^{-5}	Risk magnitude, percent contribution to total excess cancer risk (14 to 19%), and high detection frequency in surface sediment samples (92%).
cPAHs	Yes	4×10^{-5}	Risk magnitude, percent contribution to total excess cancer risk (3 to 85%), and high detection frequency in surface sediment samples (94%).
PCBs	Yes	8×10^{-6}	Lower risk magnitude and percent contribution to total excess cancer risk than the other sediment risk drivers, but selected because of importance in the seafood consumption scenarios.
Dioxins/furans	Yes	1×10^{-4}	Risk magnitude, percent contribution to total excess cancer risk (35 to 72%), and high detection frequency in surface sediment samples (100%).
Toxaphene	No	6×10^{-6}	Low percent contribution to total excess cancer risk (6% or less) and low detection frequency in surface sediment samples (1%).

Notes:

a. Only RME scenarios were used to designate COCs. The highest risk estimate for any of the RME scenarios is shown in this table. Note that the estimates reported here differ slightly from those reported in Appendix B of the RI (the HHRA) (Windward 2007b), and Section 6 of the RI (Windward 2010). The apportionment of shellfish (i.e., the amount of crab consumed relative to other shellfish but not the total quantity consumed) for scenarios based on the Tulalip Tribes survey was updated in response to an EPA correction). The influence of this correction on the total risk estimates is relatively minor. This change and its impact on risk estimates were described in detail in an erratum (Windward 2009) to the HHRA (Windward 2007b).

BHC = benzene hexachloride; cPAH = carcinogenic polycyclic aromatic hydrocarbon; COC = contaminant of concern; HHRA = human health risk assessment; DDT = dichlorodiphenyltrichloroethane; HQ = hazard quotient; J = estimated concentration; N = tentative identification; nd = no data; PCB = polychlorinated biphenyl; RI = remedial investigation; RL = reporting limit; RME = reasonable maximum exposure

Table 3-9 Sediment RBTCs for Total PCBs Based on the Human Health RME Seafood Consumption Scenarios and on Seafood Consumption by River Otters

Seafood Consumption Scenario	Sediment RBTCs for Total PCBs (µg/kg dw)			
	1 in 1,000,000 Risk Level (1×10^{-6})	1 in 100,000 Risk Level (1×10^{-5})	1 in 10,000 Risk Level (1×10^{-4})	HQ = 1
Human Health				
Adult Tribal RME (Tulalip data)	<1[a]	<1[a]	7.3	<1
Child Tribal RME (Tulalip data)	<1[a]	<1[a]	185	<1
Adult API RME	<1[a]	<1[a]	100	<1
Ecological				
River otter	n/a	n/a	n/a	128 – 159[b]

Notes:

a. Sediment RBTCs are reported as < 1 µg/kg because even if total PCB sediment concentrations were assumed to be 0 µg/kg dw, water concentrations would need to be well below upstream concentrations (which are currently 0.3 ng/L on average) to calculate concentrations in tissue that would equate to these lower risk levels. Only at hypothetical water concentrations that are not believed to be achievable for the LDW are the sediment RBTCs for the 1×10^{-5} or 1×10^{-6} risk levels greater than 0 µg/kg dw (Figure 3-2). For example, using a hypothetical water concentration of 0.01 ng/L, the sediment RBTC would be greater than 0 for the 1×10^{-5} risk level.

b. Represents best-fit estimates for two different river otter dietary scenarios as presented in the ERA (Windward 2007a).

API = Asian and Pacific Islander; dw = dry weight; ERA = ecological risk assessment; HQ = hazard quotient; kg = kilograms; L = liter; µg = micrograms; n/a = not applicable; ng = nanograms; PCB = polychlorinated biphenyl; RBTC = risk-based threshold concentration; RME = reasonable maximum exposure

Table 3-10 Sediment RBTCs for Human Health Direct Sediment Contact RME Exposure Scenarios

Risk Driver	Target Risk	Sediment RBTC		
		Netfishing RME	Beach Play RME	Tribal Clamming RME
Arsenic (mg/kg dw)	1×10^{-6}	3.7	2.8	1.3
	1×10^{-5}	37	28	13
	1×10^{-4}	370	280	130
cPAH TEQ[a] (µg/kg dw)	1×10^{-6}	380	90	150
	1×10^{-5}	3,800	900	1,500
	1×10^{-4}	38,000	9,000	15,000
Dioxins/furan TEQ[b] (ng/kg dw)	1×10^{-6}	37	28	13
	1×10^{-5}	370	280	130
	1×10^{-4}	3,700	2,800	1,300
Total PCBs (µg/kg dw)	1×10^{-6}	1,300	1,700	500
	1×10^{-5}	13,000	17,000	5,000
	1×10^{-4}	130,000	170,000	50,000
	HQ = 1	n/a[c]	5,900	n/a[c]

Notes:

a. cPAHs are presented as benzo(a)pyrene TEQs.

b. Dioxins/furans are presented as 2,3,7,8-TCDD mammalian TEQs.

c. Sediment RBTCs were calculated for non-cancer risk (HQ of 1) only when HQs were greater than 1 for a given scenario-risk driver combination.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; HQ = hazard quotient; kg = kilograms; µg = micrograms; mg =milligrams; n/a = not applicable; ng = nanograms; PCB = polychlorinated biphenyl; RBTC = risk-based threshold concentration; RME = reasonable maximum exposure; TCDD = tetrachlorodibenzo-p-dioxin; TEQ = toxic equivalent

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

Risk Driver	Target Risk	Ingestion-weighted Tissue RBTC[a]			
		Excess Cancer Risk			Non-cancer Hazard
		1×10^{-6}	1×10^{-5}	1×10^{-4}	HQ = 1
Arsenic (mg/kg ww)	Adult Tribal RME (Tulalip Data)	0.00056	0.0056	0.056	0.25
	Child Tribal RME (Tulalip Data)	0.0030	0.030	0.30	0.12
	Adult API RME	0.0019	0.019	0.19	0.37
cPAH TEQ[b] (µg/kg ww)	Adult Tribal RME (Tulalip Data)	0.11	1.1	11	n/a
	Child Tribal RME (Tulalip Data)	0.12[c]	1.2[c]	12[c]	n/a
	Adult API RME	0.39	3.9	39	n/a
Dioxin/furan TEQ[d] (ng/kg ww)	Adult Tribal RME (Tulalip Data)	0.0056	0.056	0.56	n/a
	Child Tribal RME (Tulalip Data)	0.030	0.30	3.0	n/a
	Adult API RME	0.019	0.19	1.9	n/a
Total PCBs (µg/kg ww)	Adult Tribal RME (Tulalip Data)	0.42	4.2	42	17
	Child Tribal RME (Tulalip Data)	2.3	23	230	7.8
	Adult API RME	1.4	14	140	24

Notes:

a. Tissue RBTCs associated with human seafood consumption scenarios were calculated using the risk equations in the baseline HHRA (Windward 2007b). These tissue RBTCs represent the ingestion-weighted average concentration in tissue (across all seafood types), resulting in a risk threshold. For example, the RBTC for total PCBs for the adult tribal RME seafood consumption scenario based on Tulalip data was 4.2 µg/kg ww at the 1×10^{-5} excess cancer risk level. Thus, consumption of 97.5 g/day (adult tribal RME daily ingestion rate based on Tulalip data) of any tissue type with a total PCB concentration of 4.2 µg/kg ww for 70 years would result in a 1×10^{-5} excess cancer risk. Consumption of numerous types of seafood, such as crabs, clams, and fish (as specified in the adult tribal RME exposure parameters based on Tulalip data) would also result in a 1×10^{-5} excess cancer risk as long as the ingestion-weighted average of the various tissue concentrations consumed was 4.2 µg/kg ww.

b. cPAHs are presented as benzo(a)pyrene TEQs.

c. Because of the potential for increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005a), the risk estimate for children for cPAHs is based on dose adjustments across the 0-to-6-year age range of children (see Appendix B of the RI, Section B.5.1, for more information).

d. Dioxins/furans are presented as 2,3,7,8-TCDD mammalian TEQs.

API = Asian and Pacific Islanders; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; EPA = U.S. Environmental Protection Agency; HQ = hazard quotient; kg = kilograms; µg = micrograms; mg =milligrams; n/a = not applicable; ng = nanograms; PCB = polychlorinated biphenyl; RBTC = risk-based threshold concentration; RI = remedial investigation; RME = reasonable maximum exposure; TCDD = tetrachlorodibenzo-*p*-dioxin; TEQ = toxic equivalent; ww = wet weight

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

RBTC equation for carcinogenic effects:

$$\mathit{Tissue\ RBTC} = \frac{TR}{\left(\left[\frac{1R \times FC \times EF \times ED \times CF}{BW \times AT_c}\right] \times SF\right)}$$

RBTC equation or non-carcinogenic effects:

$$\mathit{Tissue\ RBTC} = \frac{THQ}{\left(\left[\frac{1R \times FC \times EF \times ED \times CF}{BW \times AT_{nc}}\right] \times \frac{1}{RfD}\right)}$$

			Parameter Values[a]		
Parameter Name	**Acronym**	**Unit**	**Adult Tribal RME (Tulalip Data)**	**Child Tribal RME (Tulalip Data)**	**Adult API RME**
Risk-based threshold concentration	RBTC	mg/kg ww	see Table 3-11 for calculated RBTCs		
Target excess cancer risk	TR	unitless	10^{-6}, 10^{-5}, 10^{-4}	10^{-6}, 10^{-5}, 10^{-4}	10^{-6}, 10^{-5}, 10^{-4}
Target HQ	THQ	unitless	1	1	1
Ingestion rate	IR	g/day	97.5	39.0	51.5
Fraction from contaminated site	FC	unitless	1	1	1
Exposure frequency	EF	days	365	365	365
Exposure duration	ED	years	70	6	30
Conversion factor	CF	kg to g	0.001	0.001	0.001
Body weight	BW	kg	81.8	15.2	63
Averaging time, cancer	AT_c	days	25,550	25,550	25,550
Averaging time, non-cancer	AT_{nc}	days	25,550	2,190	10,950
Slope factor	SF	$(mg/kg\text{-}day)^{-1}$	toxicity values are contaminant-specific (Total PCBs = 2; Inorganic arsenic = 1.5; cPAH TEQ = 7.3; dioxin/furan TEQ = 150,000)		
Reference dose	RfD	mg/kg-day	toxicity values are contaminant-specific (Total PCBs = 0.00002; Inorganic arsenic = 0.0003)		

Notes:

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

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

Table 3-13 Comparison of Tissue RBTCs for the Adult Tribal RME Scenario Based on Tulalip Data and Non-Urban Puget Sound Tissue Data

	RBTCs for 10^{-4} Risk Level[a]		RBTCs for 10^{-5} Risk Level[a]		RBTCs for 10^{-6} Risk Level[a]		RBTCs for HQ = 1[a]			Non-Urban Puget Sound Tissue Data[c]			
Species Categories	**Total Seafood Diet**	**Species-Specific[d]**	**Total Seafood Diet**	**Species-Specific[d]**	**Total Seafood Diet**	**Species-Specific[d]**	**Total Seafood Diet**	**Species-Specific[d]**	**LDW HHRA Average Conc.[b]**	**Detection Frequency**	**Range of Detects**	**Mean Value[e]**	**Species Types**
Total PCBs (µg/kg ww)													
Benthic fish, fillet[f]	42	75	4.2	7.5	0.42	0.75	17	30	700	158 / 242	1.3 – 75.4	11	English sole, rock sole
Pelagic fish		181		18		1.8		73	1,700	n/a	n/a	n/a	n/a
Crab, edible meat		18		1.8		0.18		7.3	170	17 / 17	0.43 – 1.92	0.86	Dungeness crab
Crab, whole body		95		9.5		0.95		38	890	15 / 15	3.03 – 16[g]	7.1[g]	Dungeness crab
Clams		15		1.5		0.15		6.0	140	24 / 70	0.09 – 1.43	0.3	Butter clam, geoduck, horse clam, littleneck clam
Inorganic arsenic (mg/kg ww)													
Benthic fish, fillet[f]	0.056	0.00039	0.0056	0.000039	0.00056	0.0000039	0.25	0.0017	0.004	3 / 12	0.002 – 0.004 J	0.002	English sole
Pelagic fish		0.0056		0.00056		0.000056		0.025	0.057	8 / 9	0.009 J – 0.03	0.02	Shiner surfperch (whole body)
Crab, edible meat		0.0022		0.00022		0.000022		0.010	0.023	12 / 12	0.01 – 0.04	0.02	Dungeness crab, slender crab
Crab, whole body		0.0073		0.00073		0.000073		0.033	0.075	12 / 12	0.032 – 0.13[g]	0.075[g]	Dungeness crab, slender crab
Clams		0.12		0.012		0.0012		0.54	1.24	24 / 24	0.044 J – 0.62 J	0.21	Eastern softshell clam, composites with multiple species (butter clam, cockle, Eastern softshell clam, littleneck clam)
cPAH TEQ (µg/kg ww)													
Benthic fish, fillet[f]	11	0.61	1.1	0.061	0.11	0.0061	np	np	0.39	0 / 1	< 0.114 (no detects)	0.114 (no detects)	Starry flounder
Pelagic fish		1.2		0.12		0.012		np	0.78	n/a	n/a	n/a	n/a
Crab, edible meat		0.69		0.069		0.0069		np	0.44	0 / 8	< 1.63 (no detects)	0.406 (no detects)	Dungeness crab
Crab, whole body		1.2		0.12		0.012		np	0.75	0 / 7	< 0.923 (no detects)[g]	0.230 (no detects)[g]	Dungeness crab
Clams		24		2.4		0.24		np	15	3 / 11	0.069 – 0.171	0.088	Butter clam, geoduck, littleneck clam
Dioxin/furan TEQ (ng/kg ww)													
Benthic fish, fillet[f]	0.56	nc	0.056	nc	0.0056	nc	np	np	n/a	4 / 4	0.166 – 0.923	0.421	Starry flounder, rock sole
Pelagic fish		nc		nc		nc		np	n/a	n/a	n/a	n/a	n/a
Crab, edible meat		nc		nc		nc		np	n/a	27 / 27	0.027 – 1.37	0.24	Dungeness crab
Crab, whole body		nc		nc		nc		np	n/a	25 / 25	0.089 – 5.12[g]	0.81[g]	Dungeness crab
Clams		nc		nc		nc		np	n/a	43 / 43	0.011 – 1.63	0.26	Butter clam, geoduck, horse clam, littleneck clam

Notes:

a. RBTCs are for the adult tribal RME scenario based on Tulalip data.

b. The LDW HHRA dataset includes tissue samples collected between 1992 and 2005. Additional tissue samples were collected from the LDW in 2007 (see Section 4 of the RI).

c. Details regarding the non-urban Puget Sound tissue dataset are presented in Section B.4 of Appendix B of the FS.

d. Species-specific tissue RBTCs are based on only the HHRA dataset. Additional species-specific tissue RBTCs are available for total PCBs and are presented in Section B.3 of Appendix B (Table B-5).

e. Mean values were calculated arithmetically when there were no non-detect results. When non-detect results were present in a given dataset, ProUCL 4 was used to calculate the Kaplan Meier mean for the dataset.

f. Whole-body benthic fish consumption is assumed to be equal to zero for the adult tribal RME scenario based on Tulalip data, and thus this category is not shown on this table. However, for informational purposes, background whole-body benthic fish data could be compared to fillet data using the fillet-to-whole body ratio developed in the RI (fillet = 0.526 x whole body).

g. When only edible meat and hepatopancreas samples were available for a given sampling event, whole-body concentrations were calculated as in the LDW HHRA.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; FS = feasibility study; HHRA = human health risk assessment; HQ = hazard quotient; kg = kilograms; LDW = Lower Duwamish Waterway; µg = micrograms; mg = milligrams; n/a = not available; nc = cannot be calculated; ng = nanograms; np = not applicable; PCB = polychlorinated biphenyl; RBTC = risk-based threshold concentration; RME = reasonable maximum exposure; TEQ =toxic equivalent; ww = wet weight

Table 3-14 Comparison of Tissue RBTCs for the Child Tribal RME Scenario Based on Tulalip Data and Non-Urban Puget Sound Tissue Data

Species Categories	RBTCs for 10^{-4} Risk Level[a]		RBTCs for 10^{-5} Risk Level[a]		RBTCs for 10^{-6} Risk Level[a]		RBTCs for HQ = 1[a]		LDW HHRA Average Conc.[b]	Non-Urban Puget Sound Tissue Data[c]			
	Total Seafood Diet	Species-Specific[d]	Total Seafood Diet	Species-Specific[d]	Total Seafood Diet	Species-Specific[d]	Total Seafood Diet	Species-Specific[d]		Detection Frequency	Range of Detects	Mean Value[e]	Species Types
Total PCBs (μg/kg ww)													
Benthic fish, fillet[f]	230	412	23	41	2.3	4.1	7.8	14	700	158 / 242	1.3 – 75.4	11	English sole, rock sole
Pelagic fish		1,000		100		10		34	1,700	n/a	n/a	n/a	n/a
Crab, edible meat		100		10		1.0		3.4	170	17 / 17	0.43 – 1.92	0.86	Dungeness crab
Crab, whole body		523		52		5.2		18	890	15 / 15	3.03 – 16[g]	7.1[g]	Dungeness crab
Clams		82		8.2		0.82		2.8	140	24 / 70	0.09 – 1.43	0.3	Butter clam, geoduck, horse clam, littleneck clam
Inorganic arsenic (mg/kg ww)													
Benthic fish, fillet[f]	0.30	0.0021	0.030	0.00021	0.0030	0.000021	0.12	0.00083	0.004	3 / 12	0.002 – 0.004 J	0.002	English sole
Pelagic fish		0.030		0.0030		0.00030		0.012	0.057	8 / 9	0.009 J – 0.03	0.02	Shiner surfperch (whole body)
Crab, edible meat		0.012		0.0012		0.00012		0.0048	0.023	12 / 12	0.01 – 0.04	0.02	Dungeness crab, slender crab
Crab, whole body		0.039		0.0039		0.00039		0.016	0.075	12 / 12	0.032 – 0.13[g]	0.075[g]	Dungeness crab, slender crab
Clams		0.65		0.065		0.0065		0.26	1.24	24 / 24	0.044 J – 0.62 J	0.21	Eastern softshell clam, composites with multiple species (butter clam, cockle, Eastern softshell clam, littleneck clam)
cPAH TEQ (μg/kg ww)													
Benthic fish, fillet[f]	12	0.66	1.2	0.066	0.12	0.0066	np	np	0.39	0 / 1	< 0.114 (no detects)	0.114 (no detects)	Starry flounder
Pelagic fish		1.3		0.13		0.013		np	0.78	n/a	n/a	n/a	n/a
Crab, edible meat		0.75		0.075		0.0075		np	0.44	0 / 8	< 1.63 (no detects)	0.406 (no detects)	Dungeness crab
Crab, whole body		1.3		0.13		0.013		np	0.75	0 / 7	< 0.923 (no detects)[g]	0.230 (no detects)[g]	Dungeness crab
Clams		26		2.6		0.26		np	15	3 / 11	0.069 – 0.171	0.088	Butter clam, geoduck, littleneck clam
Dioxin/furan TEQ (ng/kg ww)													
Benthic fish, fillet[f]	3.0	nc	0.30	nc	0.030	nc	np	np	n/a	4 / 4	0.166 – 0.923	0.421	Starry flounder, rock sole
Pelagic fish		nc		nc		nc		np	n/a	n/a	n/a	n/a	n/a
Crab, edible meat		nc		nc		nc		np	n/a	27 / 27	0.027 – 1.37	0.24	Dungeness crab
Crab, whole body		nc		nc		nc		np	n/a	25 / 25	0.089 – 5.12[g]	0.81[g]	Dungeness crab
Clams		nc		nc		nc		np	n/a	43 / 43	0.011 – 1.63	0.26	Butter clam, geoduck, horse clam, littleneck clam

Notes:

a. RBTCs are for the child tribal RME scenario based on Tulalip data.

b. The LDW HHRA dataset includes tissue samples collected between 1992 and 2005. Additional tissue samples were collected from the LDW in 2007 (see Section 4 of the RI).

c. Details regarding the non-urban Puget Sound tissue dataset are presented in Section B.4 of Appendix B of the FS.

d. Species-specific tissue RBTCs are based on only the HHRA dataset. Additional species-specific tissue RBTCs are available for total PCBs and are presented in Section B.3 of Appendix B (Table B-6).

e. Mean values were calculated arithmetically when there were no non-detect results. When non-detect results were present in a given dataset, ProUCL 4 was used to calculate the Kaplan Meier mean for the dataset.

f. Whole-body benthic fish consumption is assumed to be equal to zero for the child tribal RME scenario based on Tulalip data, and thus this category is not shown on this table. However, for informational purposes, background whole-body benthic fish data could be compared to fillet data using the fillet-to-whole body ratio developed in the RI (fillet = 0.526 x whole body).

g. When only edible meat and hepatopancreas samples were available for a given sampling event, whole-body concentrations were calculated as in the LDW HHRA.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; FS = feasibility study; HHRA = human health risk assessment; HQ = hazard quotient; kg = kilograms; LDW = Lower Duwamish Waterway; μg = micrograms; mg = milligrams; n/a = not available; nc = cannot be calculated; ng = nanograms; np = not applicable; PCB = polychlorinated biphenyl; RBTC = risk-based threshold concentration; RME = reasonable maximum exposure; TEQ =toxic equivalent; ww = wet weight

Table 3-15 Comparison of Tissue RBTCs for the Adult API RME Scenario and Non-Urban Puget Sound Tissue Data

	RBTCs for 10^{-4} Risk Level[a]		RBTCs for 10^{-5} Risk Level[a]		RBTCs for 10^{-6} Risk Level[a]		RBTCs for HQ = 1[a]			Non-Urban Puget Sound Tissue Data[c]			
Species Categories	**Total Seafood Diet**	**Species-Specific[d]**	**Total Seafood Diet**	**Species-Specific[d]**	**Total Seafood Diet**	**Species-Specific[d]**	**Total Seafood Diet**	**Species-Specific[d]**	**LDW HHRA Average Conc.[b]**	**Detection Frequency**	**Range of Detects**	**Mean Value[e]**	**Species Types**
Total PCBs (µg/kg ww)													
Benthic fish, fillet[f]	140	230	14	23	1.4	2.3	24	39	700	158 / 242	1.3 – 75.4	11	English sole, rock sole
Benthic fish, whole body		723		72		7.2		124	2,200	n/a	n/a	n/a	n/a
Pelagic fish		559		56		5.6		96	1,700	n/a	n/a	n/a	n/a
Crab, edible meat		56		5.6		0.56		9.6	170	17 / 17	0.43 – 1.92	0.86	Dungeness crab
Crab, whole body		293		29		2.9		50	890	15 / 15	3.03 – 16[g]	7.1[g]	Dungeness crab
Clams		46		4.6		0.46		7.9	140	24 / 70	0.09 – 1.43	0.3	Butter clam, geoduck, horse clam, littleneck clam
Inorganic arsenic (mg/kg ww)													
Benthic fish, fillet[f]	0.19	0.00097	0.019	0.000097	0.0019	0.0000097	0.37	0.0019	0.004	3 / 12	0.002 – 0.004 J	0.002	English sole
Benthic fish, whole body		0.014		0.0014		0.00014		0.026	0.056	12 / 12	0.007 J – 0.03	0.01	English sole
Pelagic fish		0.014		0.0014		0.00014		0.027	0.057	8 / 9	0.009 J – 0.03	0.02	Shiner surfperch (whole body)
Crab, edible meat		0.0056		0.00056		0.000056		0.011	0.023	12 / 12	0.01 – 0.04	0.02	Dungeness crab, slender crab
Crab, whole body		0.018		0.0018		0.00018		0.035	0.075	12 / 12	0.032 – 0.13[g]	0.075[g]	Dungeness crab, slender crab
Clams		0.30		0.030		0.0030		0.59	1.24	24 / 24	0.044 J – 0.62 J	0.21	Eastern softshell clam, composites with multiple species (butter clam, cockle, Eastern softshell clam, littleneck clam)
cPAH TEQ (µg/kg ww)													
Benthic fish, fillet[f]	39	1.6	3.9	0.16	0.39	0.016	np	np	0.39	0 / 1	< 0.114 (no detects)	0.114 (no detects)	Starry flounder
Benthic fish, whole body		5.7		0.57		0.057		np	1.4	n/a	n/a	n/a	n/a
Pelagic fish		3.2		0.32		0.032		np	0.78	n/a	n/a	n/a	n/a
Crab, edible meat		1.8		0.18		0.018		np	0.44	0 / 8	< 1.63 (no detects)	0.406 (no detects)	Dungeness crab
Crab, whole body		3.1		0.31		0.031		np	0.75	0 / 7	< 0.923 (no detects)[g]	0.230 (no detects)[g]	Dungeness crab
Clams		61		6.1		0.61		np	15	3 / 11	0.069 – 0.171	0.088	Butter clam, geoduck, littleneck clam
Dioxin/furan TEQ (ng/kg ww)													
Benthic fish, fillet[f]	1.9	nc	0.19	nc	0.019	nc	np	np	n/a	4 / 4	0.166 – 0.923	0.421	Starry flounder, rock sole
Benthic fish, whole body		nc		nc		nc		np	n/a	7 / 7	0.152 – 0.417	0.281	English sole, rock sole
Pelagic fish		nc		nc		nc		np	n/a	n/a	n/a	n/a	n/a
Crab, edible meat		nc		nc		nc		np	n/a	27 / 27	0.027 – 1.37	0.24	Dungeness crab
Crab, whole body		nc		nc		nc		np	n/a	25 / 25	0.089 – 5.12[g]	0.81[g]	Dungeness crab
Clams		nc		nc		nc		np	n/a	43 / 43	0.011 – 1.63	0.26	Butter clam, geoduck, horse clam, littleneck clam

Notes:

a. RBTCs are for the adult API RME scenario.

b. The LDW HHRA dataset includes tissue samples collected between 1992 and 2005. Additional tissue samples were collected from the LDW in 2007 (see Section 4 of the RI).

c. Details regarding the non-urban Puget Sound tissue dataset are presented in Section B.4 of Appendix B of the FS.

d. Species-specific tissue RBTCs are based on only the HHRA dataset. Additional species-specific tissue RBTCs are available for total PCBs and are presented in Section B.3 of Appendix B (Table B-7).

e. Mean values were calculated arithmetically when there were no non-detect results. When non-detect results were present in a given dataset, ProUCL 4 was used to calculate the Kaplan Meier mean for the dataset.

f. For informational purposes, background whole-body benthic fish data could be compared to fillet data using the fillet-to-whole body ratio developed in the RI (fillet = 0.526 x whole body).

g. When only edible meat and hepatopancreas samples were available for a given sampling event, whole-body concentrations were calculated as in the LDW HHRA.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; FS = feasibility study; HHRA = human health risk assessment; HQ = hazard quotient; kg = kilograms; LDW = Lower Duwamish Waterway; µg = micrograms; mg = milligrams; n/a = not available; nc = cannot be calculated; ng = nanograms; np = not applicable; PCB = polychlorinated biphenyl; RBTC = risk-based threshold concentration; RME = reasonable maximum exposure; TEQ =toxic equivalent; ww = wet weight

Table 3-16 Summary of Risk Screening and Identification of COCs and Risk Drivers

MTCA Terminology	CERCLA Terminology	Contaminants			
		Human Health Seafood Consumption	**Human Health Direct Sediment Contact**	**Benthic Invertebrate Community**	**Other Ecological Receptors**
STEP 1 – Conduct conservative risk-based screening to identify COPCs *Ecological: COPCs are contaminants with maximum exposure concentrations greater than TRVs.* *Human Health: COPCs are contaminants with maximum sediment concentrations greater than the EPA Region 9 RBCs; and/or the maximum seafood tissue concentrations greater than the adjusted EPA Region 3 RBCs.*					
Hazardous substances	COPCs	59 COPCs, including metals, PAHs, PCBs, organochlorine pesticides, and other SVOCs	Beach play and clamming – 28 COPCs Netfishing – 20 COPCs, including metals, PCBs, arsenic, cPAHs, dioxins/furans, toxaphene, and other contaminants	**Benthic invertebrates** – 41 COPCs including metals, PAHs, PCBs, phthalates, and other SVOCs based on detected exceedance of SQS in surface sediment at one or more locations; non-SMS contaminants – TBT; nickel; total DDTs; total chlordane; cis-1,2-dichloroethene	**Crabs** – zinc and PCBs **Fish** – arsenic, cadmium, copper, vanadium, PCBs, TBT, dioxins/furans **Birds** – arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, vanadium, zinc, PCBs, dioxins/furans **Mammals** – arsenic, cobalt, mercury, selenium, PCBs, dioxins/furans
STEP 2 – Compare risk estimates to thresholds to identify COCs for both human health and ecological receptors *Ecological: COCs are contaminants with LOAEL-based HQs greater than or equal to 1.0.* *Human Health: COCs are contaminants with excess cancer risk estimates greater than 1×10^{-6} or an HQ greater than 1 for any RME scenario.*					
Hazardous substances	COCs	PCBs, arsenic, cPAHs, dioxins/furans, BEHP, pentachlorophenol, TBT, vanadium, and 11 tentatively identified compounds (aldrin, alpha-BHC, beta-BHC, carbazole, total chlordane, total DDTs, dieldrin, gamma-BHC, heptachlor, heptachlor epoxide, hexachlorobenzene)[a]	PCBs, arsenic, cPAHs, dioxins/furans, toxaphene	**Benthic invertebrates** – 41 COCs above SQS; non-SMS contaminants – nickel, total DDTs, total chlordane	**Crabs** – PCBs **Fish** – cadmium, vanadium, PCBs **Birds** – chromium, copper, lead, mercury, vanadium, PCBs **Mammals** – PCBs
STEP 3 – Apply weight-of-evidence approach to identify risk drivers *Ecological: Selection based on risk estimates, uncertainties discussed in the baseline ERA, natural background concentrations and residual risk following planned early actions in the LDW.* *Human Health: Selection based on magnitude of risk and relative percentage of total human health risk posed by the COC and indicator hazardous substance criteria set forth in WAC 173-340-703.*					
Indicator hazardous substances	Risk drivers[b]	Total PCBs, arsenic, cPAHs, dioxins/furans[c]	Total PCBs, arsenic, cPAHs, dioxins/furans	**Benthic invertebrates** – 41 COCs above SQS[d]	**Mammals** (river otter) – total PCBs

Notes:

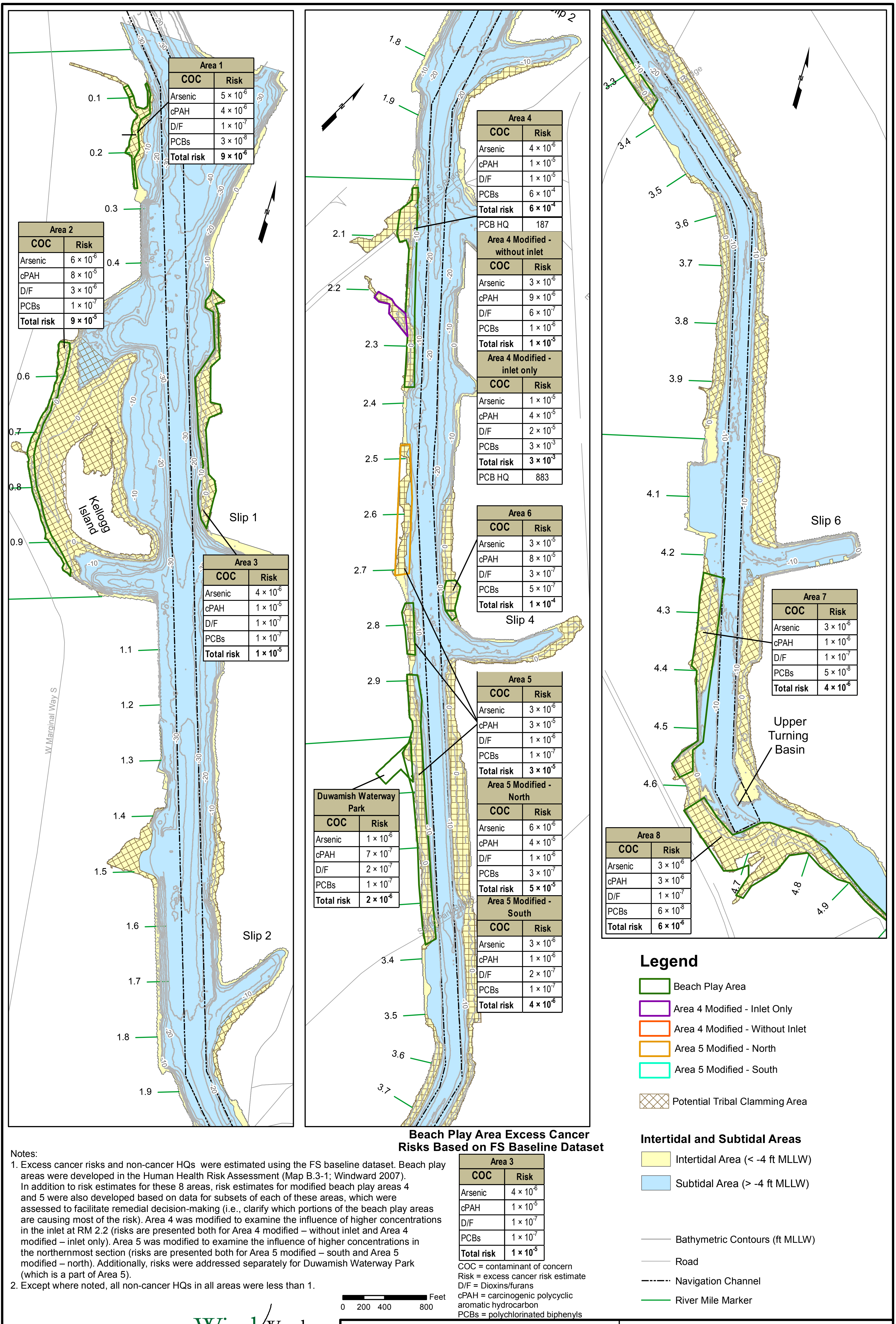
a. Organochlorine pesticides were qualified as tentatively identified compounds at estimated concentrations (JN-qualified), indicating uncertainty regarding both their presence and concentration.

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

c. Risks were assumed to be unacceptable; no quantitative risk analysis was performed for dioxins and furans via the seafood consumption pathway.

d. The 41 risk-drivers for the benthic community are: total PCBs, BEHP, chromium, arsenic, mercury, lead, zinc, copper, cadmium, silver, fluoranthene, butyl benzyl phthalate, indeno(1,2,3-cd)pyrene, phenol, benzo(g,h,i)perylene, benzoic acid, dibenzo(a,h)anthracene, total benzofluoranthenes, 4-methylphenol, phenanthrene, total high-molecular-weight PAHs, acenaphthene, fluorene, benzo(a)anthracene, dibenzofuran, benzo(a)pyrene, total low-molecular-weight PAHs, pyrene, 1,4-dichlorobenzene, 1,2-dichlorobenzene, 2-methylnaphthalene, dimethyl phthalate, naphthalene, n-nitrosodiphenylamine, hexachlorobenzene, benzyl alcohol, chrysene, 1,2,4-trichlorobenzene, 2,4-dimethylphenol, anthracene, and pentachlorophenol.

BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; COC = contaminant of concern; COPC = contaminant of potential concern; cPAH = carcinogenic polycyclic aromatic hydrocarbon; DDT = dichlorodiphenyltrichloroethane; EPA = U.S. Environmental Protection Agency; ERA = ecological risk assessment; HQ = hazard quotient; LDW = Lower Duwamish Waterway; LOAEL = lowest-observed-adverse-effect level; MTCA = Model Toxics Control Act; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; RBC = risk-based concentration; RME = reasonable maximum exposure; SMS = Washington State Sediment Management Standards; SQS = sediment quality standard; SVOC = semivolatile organic compound; TBT = tributyltin; TRV = toxicity reference value; WAC = Washington Administrative Code



Area 1

COC	Risk
Arsenic	5×10^{-6}
cPAH	4×10^{-6}
D/F	1×10^{-7}
PCBs	3×10^{-8}
Total risk	$\mathbf{9 \times 10^{-6}}$

Area 2

COC	Risk
Arsenic	6×10^{-6}
cPAH	8×10^{-5}
D/F	3×10^{-6}
PCBs	1×10^{-7}
Total risk	$\mathbf{9 \times 10^{-5}}$

Area 3

COC	Risk
Arsenic	4×10^{-6}
cPAH	1×10^{-5}
D/F	1×10^{-7}
PCBs	1×10^{-7}
Total risk	$\mathbf{1 \times 10^{-5}}$

Area 4

COC	Risk
Arsenic	4×10^{-6}
cPAH	1×10^{-5}
D/F	1×10^{-5}
PCBs	6×10^{-4}
Total risk	$\mathbf{6 \times 10^{-4}}$
PCB HQ	187

Area 4 Modified - without inlet

COC	Risk
Arsenic	3×10^{-6}
cPAH	9×10^{-6}
D/F	6×10^{-7}
PCBs	1×10^{-6}
Total risk	$\mathbf{1 \times 10^{-5}}$

Area 4 Modified - inlet only

COC	Risk
Arsenic	1×10^{-5}
cPAH	4×10^{-5}
D/F	2×10^{-5}
PCBs	3×10^{-3}
Total risk	$\mathbf{3 \times 10^{-3}}$
PCB HQ	883

Area 6

COC	Risk
Arsenic	3×10^{-5}
cPAH	8×10^{-5}
D/F	3×10^{-7}
PCBs	5×10^{-7}
Total risk	$\mathbf{1 \times 10^{-4}}$

Area 5

COC	Risk
Arsenic	3×10^{-6}
cPAH	3×10^{-5}
D/F	1×10^{-6}
PCBs	1×10^{-7}
Total risk	$\mathbf{3 \times 10^{-5}}$

Area 5 Modified - North

COC	Risk
Arsenic	6×10^{-6}
cPAH	4×10^{-5}
D/F	1×10^{-6}
PCBs	3×10^{-7}
Total risk	$\mathbf{5 \times 10^{-5}}$

Area 5 Modified - South

COC	Risk
Arsenic	3×10^{-6}
cPAH	1×10^{-6}
D/F	2×10^{-7}
PCBs	1×10^{-7}
Total risk	$\mathbf{4 \times 10^{-6}}$

Duwamish Waterway Park

COC	Risk
Arsenic	1×10^{-6}
cPAH	7×10^{-7}
D/F	2×10^{-7}
PCBs	1×10^{-7}
Total risk	$\mathbf{2 \times 10^{-6}}$

Area 7

COC	Risk
Arsenic	3×10^{-6}
cPAH	1×10^{-6}
D/F	1×10^{-7}
PCBs	5×10^{-8}
Total risk	$\mathbf{4 \times 10^{-6}}$

Area 8

COC	Risk
Arsenic	3×10^{-6}
cPAH	3×10^{-6}
D/F	1×10^{-7}
PCBs	6×10^{-8}
Total risk	$\mathbf{6 \times 10^{-6}}$

Beach Play Area Excess Cancer Risks Based on FS Baseline Dataset

Area 3

COC	Risk
Arsenic	4×10^{-6}
cPAH	1×10^{-5}
D/F	1×10^{-7}
PCBs	1×10^{-7}
Total risk	$\mathbf{1 \times 10^{-5}}$

COC = contaminant of concern
Risk = excess cancer risk estimate
D/F = Dioxins/furans
cPAH = carcinogenic polycyclic aromatic hydrocarbon
PCBs = polychlorinated biphenyls

Notes:

1. Excess cancer risks and non-cancer HQs were estimated using the FS baseline dataset. Beach play areas were developed in the Human Health Risk Assessment (Map B.3-1; Windward 2007). In addition to risk estimates for these 8 areas, risk estimates for modified beach play areas 4 and 5 were also developed based on data for subsets of each of these areas, which were assessed to facilitate remedial decision-making (i.e., clarify which portions of the beach play areas are causing most of the risk). Area 4 was modified to examine the influence of higher concentrations in the inlet at RM 2.2 (risks are presented both for Area 4 modified – without inlet and Area 4 modified – inlet only). Area 5 was modified to examine the influence of higher concentrations in the northernmost section (risks are presented both for Area 5 modified – south and Area 5 modified – north). Additionally, risks were addressed separately for Duwamish Waterway Park (which is a part of Area 5).
2. Except where noted, all non-cancer HQs in all areas were less than 1.

AECOM

Wind Ward environmental LLC

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway
Final Feasibility Study
60150279-14.35

Beach Play Areas with Excess Cancer Risks and Non-Cancer HQs for Risk Drivers and Clamming Areas

DATE: 10/31/12 | DWRN:MVI/CEH | Revision: 5 | **FIGURE 3-1**

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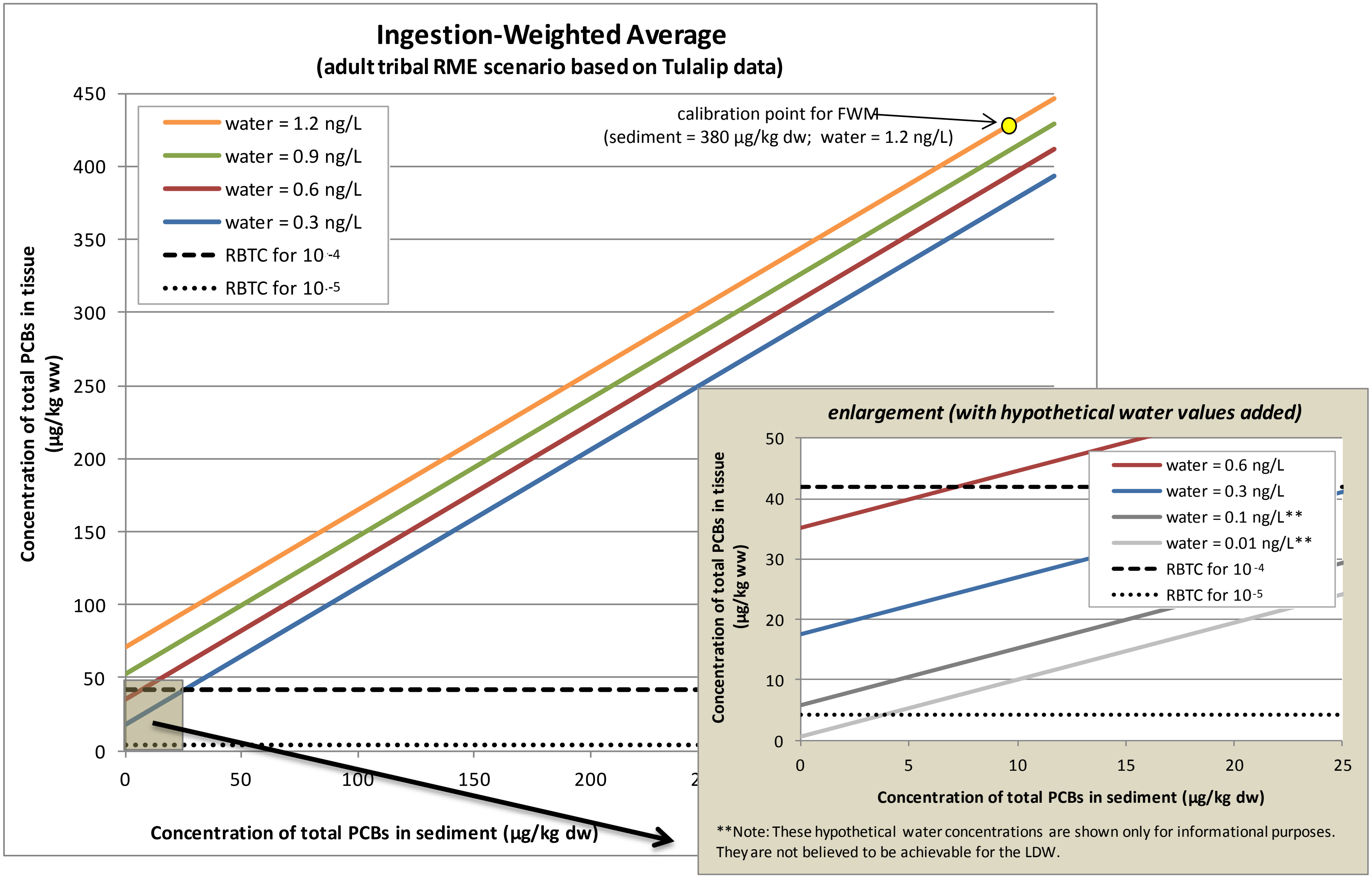
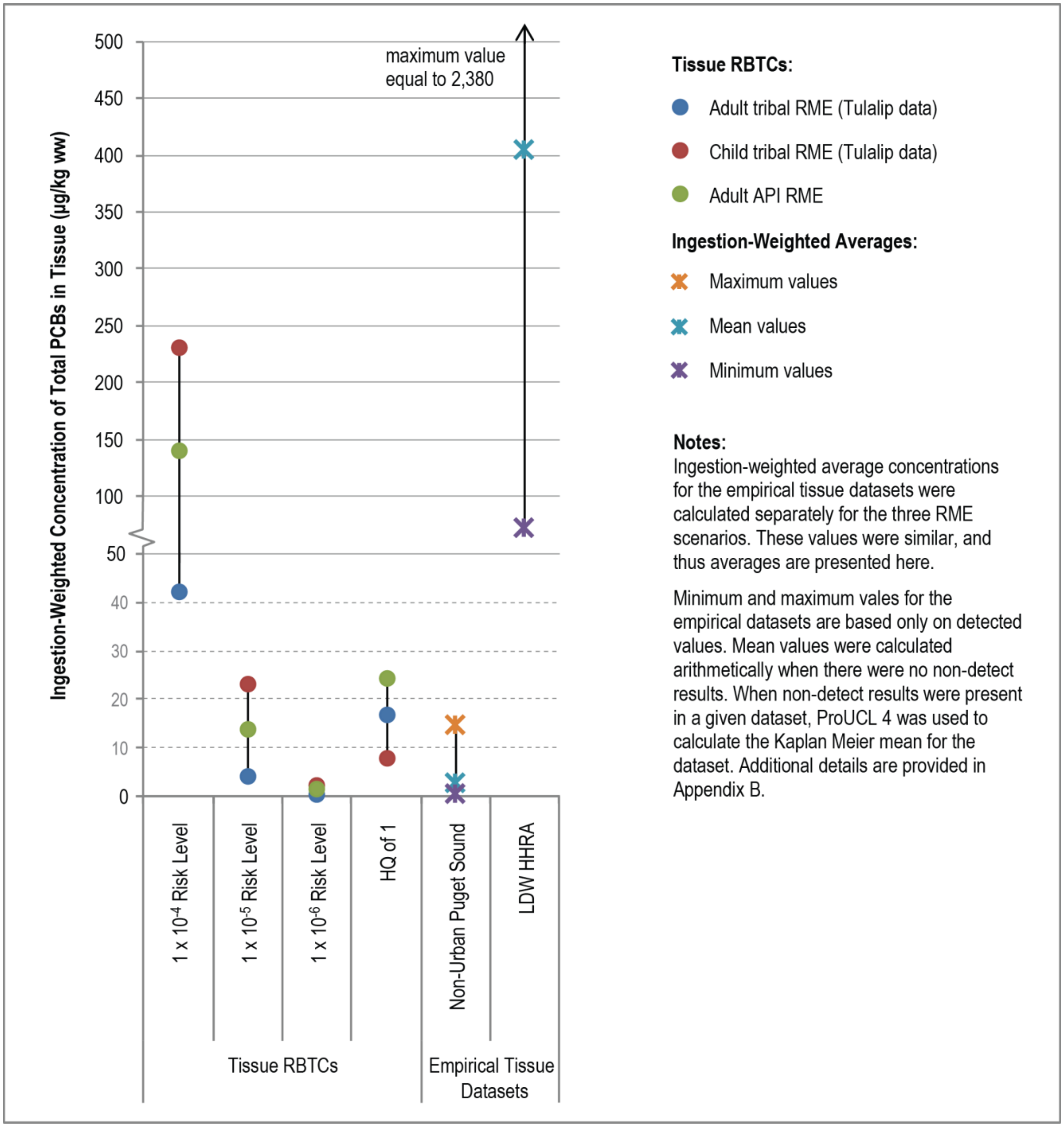
Figure 3-2 FWM-Predicted Ingestion-Weighted Average Concentrations of Total PCBs in Tissue as a Function of Concentrations in Sediment at Various Water Concentrations



**Note: These hypothetical water concentrations are shown only for informational purposes. They are not believed to be achievable for the LDW.

Figure 3-3 Comparison of Total PCB RBTCs with Ingestion-Weighted Average Concentrations from LDW and Non-Urban Puget Sound Tissue Datasets

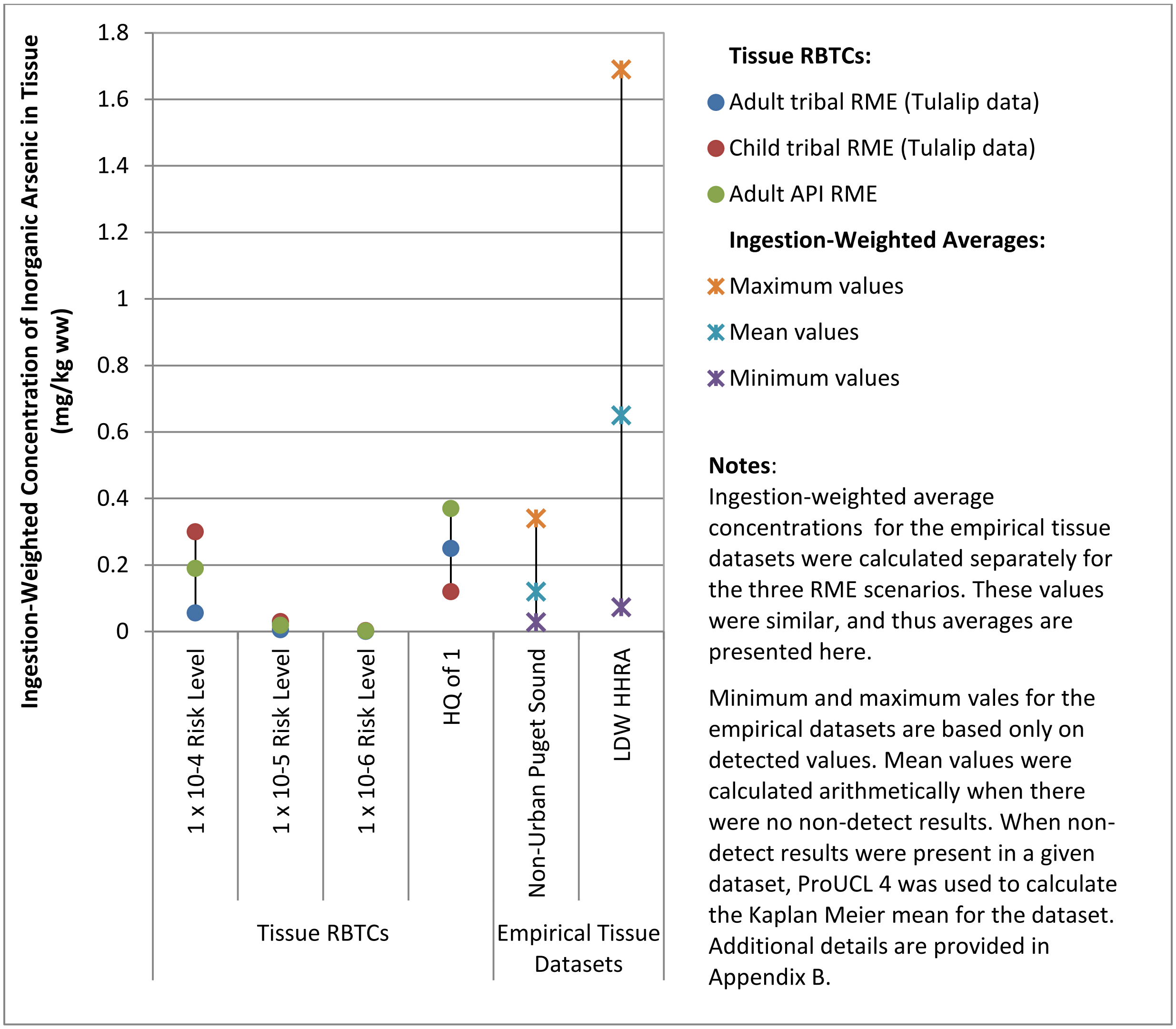


Notes:

Ingestion-weighted average concentrations for the empirical tissue datasets were calculated separately for the three RME scenarios. These values were similar, and thus averages are presented here.

Minimum and maximum vales for the empirical datasets are based only on detected values. Mean values were calculated arithmetically when there were no non-detect results. When non-detect results were present in a given dataset, ProUCL 4 was used to calculate the Kaplan Meier mean for the dataset. Additional details are provided in Appendix B.

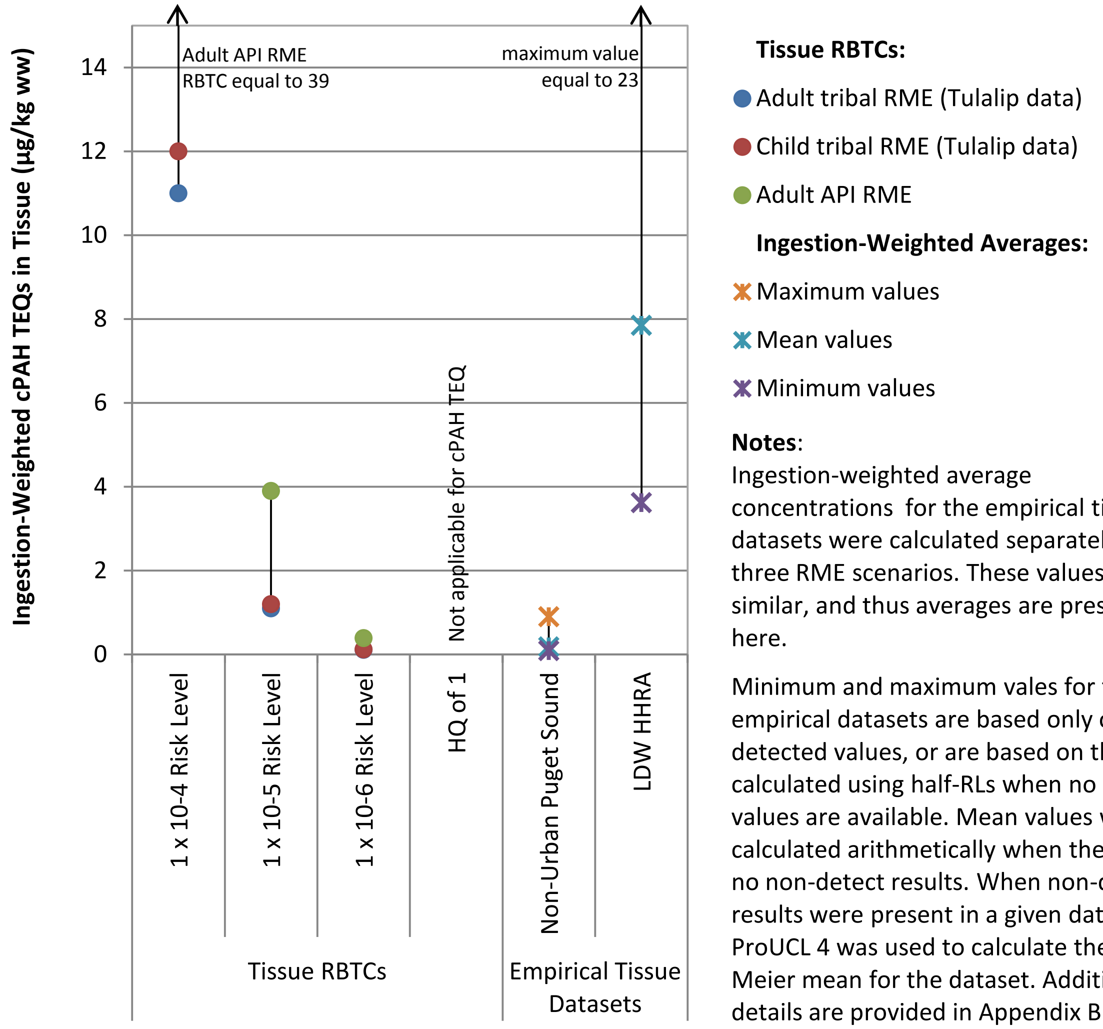
Figure 3-4 Comparison of Inorganic Arsenic RBTCs with Ingestion-Weighted Average Concentrations from LDW and Non-Urban Puget Sound Tissue Datasets



Notes:
Ingestion-weighted average concentrations for the empirical tissue datasets were calculated separately for the three RME scenarios. These values were similar, and thus averages are presented here.

Minimum and maximum vales for the empirical datasets are based only on detected values. Mean values were calculated arithmetically when there were no non-detect results. When non-detect results were present in a given dataset, ProUCL 4 was used to calculate the Kaplan Meier mean for the dataset. Additional details are provided in Appendix B.

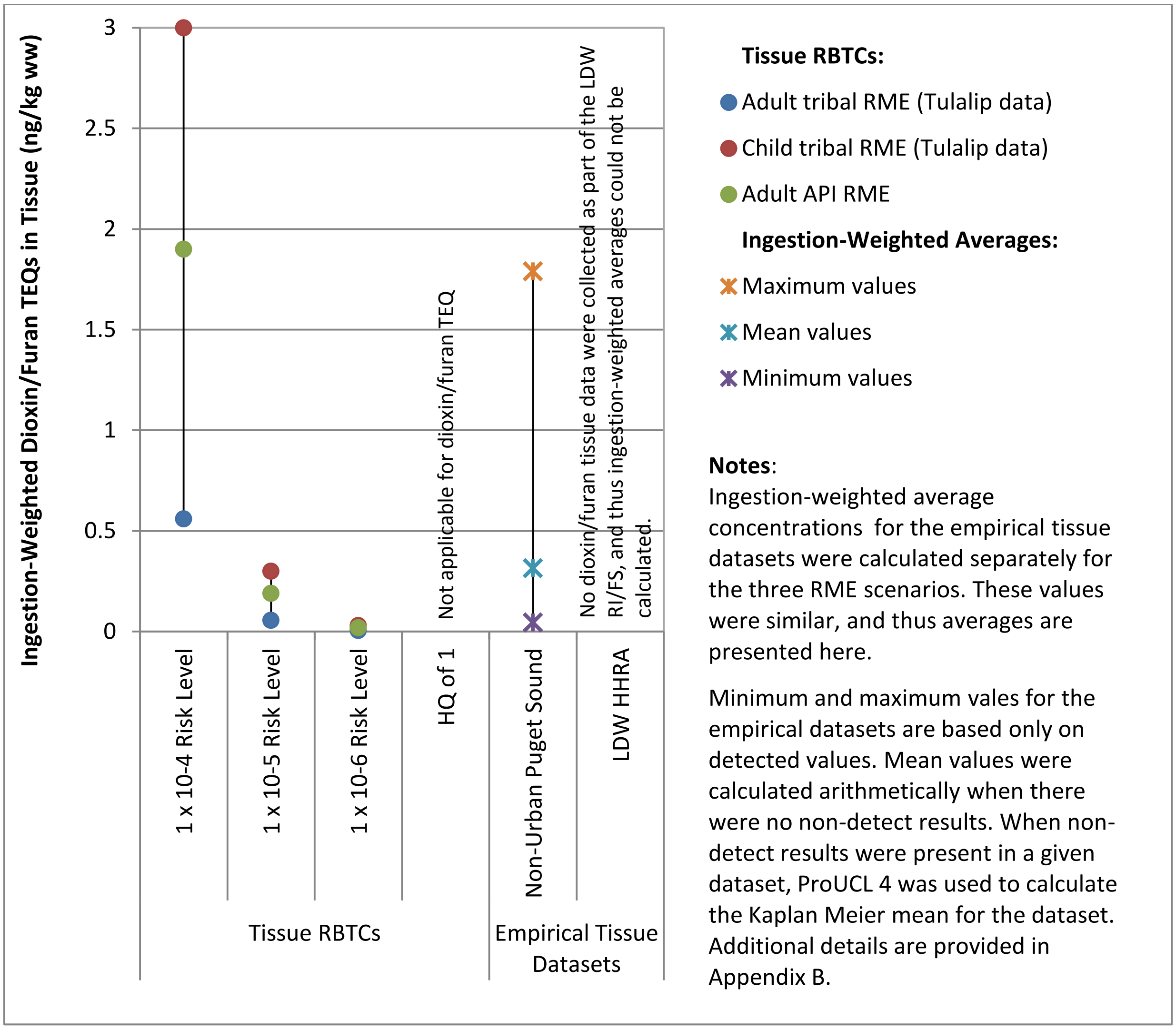
Figure 3-5 Comparison of cPAH RBTCs with Ingestion-Weighted Average Concentrations from LDW and Non-Urban Puget Sound Tissue Datasets



Notes:
Ingestion-weighted average concentrations for the empirical tissue datasets were calculated separately for the three RME scenarios. These values were similar, and thus averages are presented here.

Minimum and maximum vales for the empirical datasets are based only on detected values, or are based on the TEQ calculated using half-RLs when no detected values are available. Mean values were calculated arithmetically when there were no non-detect results. When non-detect results were present in a given dataset, ProUCL 4 was used to calculate the Kaplan Meier mean for the dataset. Additional details are provided in Appendix B.

Figure 3-6 Comparison of Dioxin/Furan RBTCs with Ingestion-Weighted Average Concentrations from LDW and Non-Urban Puget Sound Tissue Datasets



Notes:

Ingestion-weighted average concentrations for the empirical tissue datasets were calculated separately for the three RME scenarios. These values were similar, and thus averages are presented here.

Minimum and maximum vales for the empirical datasets are based only on detected values. Mean values were calculated arithmetically when there were no non-detect results. When non-detect results were present in a given dataset, ProUCL 4 was used to calculate the Kaplan Meier mean for the dataset. Additional details are provided in Appendix B.